AD-A122 843 ENGINES/FUELS WORKSHOP 6-8 DECEMBER 1982 SAN ANTONIO 1/3
TEXAS(U) SOUTHWEST RESEARCH INST SAN ANTONIO TX ARMY
FUELS AND LUBRICANTS RESEARCH LAB D M MANN ET AL. 1982
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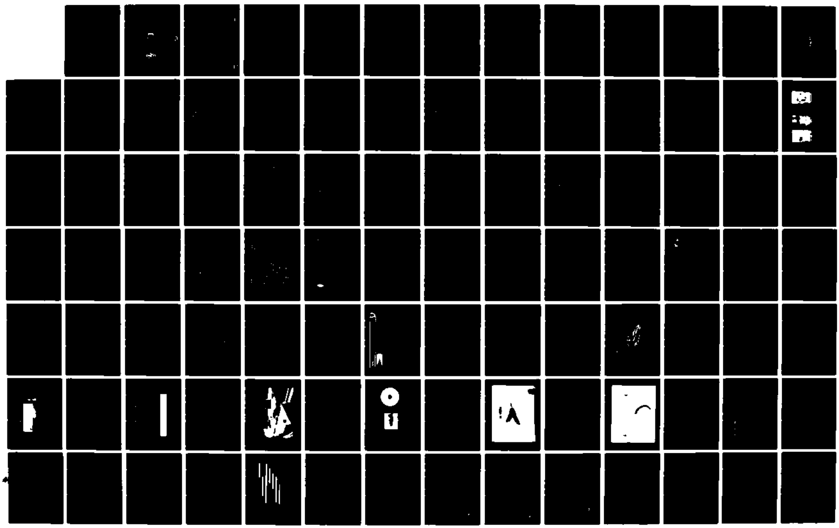

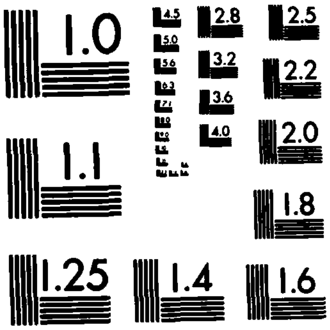

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

ENGINES/FUELS WORKSHOP

6-8 December 1982
San Antonio, Texas

Sponsored by

U.S. Army Research Office
(Research Triangle Park, NC)

and

U.S. Army Mobility Equipment Research and
Development Command
(Ft. Belvoir, VA)

Hosted by

U.S. Army Fuels and Lubricants Research Laboratory
Southwest Research Institute
(San Antonio, TX)

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Diesel Engine Combustion	Gas Turbine Engine Combustion
Diesel Engines	Gas Turbine Engines
Adiabatic Diesel Engine	Multifuel Engines

continued

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

A basic research workshop was attended by 55 university, government, and industry personnel on 6-8 December 1982. This conference was sponsored jointly by the Army Research Office and the Army Mobility Equipment Research and Development Command. The conference was arranged and hosted by the U.S. Army Fuels and Lubricants Research Laboratory, Southwest Research Institute.

continued

19. continued

Army Mobility Fuels Research
Army Ground Vehicle Engines Research
Army Aviation Turbine Engine Research
Engines/Fuels Interface
Alternative Fuels
Fuel Properties

20. continued -

The objectives were to identify engines/fuels development technical research barriers. The results of enthusiastic group participation in the conference deliberations provided substantial guidance for establishing priorities for Army basic and applied research.

Foreword

This document comprises a collection of advance information provided by the individual workshop authors/presenters. Abstracts and copies of visual aids (as provided by the authors) are reproduced for use by workshop participants and other interested parties. It has been prepared under Contract No. DAAK70-82-C-0001 with Mr. F. W. Schaekel, DRDME-GL, serving as Contracting Officer's Representative. Funds were provided jointly by the U. S. Army Research Office and the U. S. Army Mobility Equipment Research and Development Command.

To facilitate and stimulate free and open discussion during the workshop, no records other than this document will be made. Acknowledgment is given to Dr. D. W. Naegeli for assistance in initial planning of the workshop. Mr. S. J. Lestz and Dr. W. D. Weatherford, Jr. handled the details of planning the workshop and communicating with participants. Ms. Beatrice Moreno provided the physical arrangements.

Special acknowledgment is given to Dr. D. M. Mann, DRXRO-EG, and Mr. M. E. LePera, DRDME-GL, for their participation, encouragement, and suggestions during the planning and implementation of the workshop. Publication of this document would not have been possible without the cheerful and efficient editorial assistance of Ms. Rebecca Sears and Mr. J. W. Pryor.

AGENDA AND TABLE OF CONTENTS
ARO/MERADCOM ENGINES/FUELS WORKSHOP

*Presented by F. W. Schaekel, USAMERADCOM

Time		Page No.
	Session 2: ARO Combustion Research	
11:05 a.m.	Chairman: D. M. Mann, ARO	2-1
11:10 a.m.	"Transient Catalytic Combustion" R. O. Buckius and R. I. Masel, University of Illinois-Urbana	2-3
11:30 a.m.	"Basic Studies of Catalytic Combustion" P. J. Marteney, United Technologies, Research Center	2-5
11:50 a.m.	"Turbulence-Combustion Interactions in Laminr and Turbulent Premixed Methane-Air V-Flames" T. Y. Toong, Massachusetts Institute of Technology	2-17
12:10 a.m.	"Preignition Oxidation Characteristics of Hydrocarbon Fuels" R. S. Cohen and N. P. Cernansky, Drexel University	2-29
12:30 p.m.	Lunch Break	----
	Session 3: ARO Diesel Engine Research	
1:40 p.m.	Chairman: P. C. Glance, TACOM	3-1
1:45 p.m.	"Diesel Sprays" N. Chigier, Carnegie-Mellon University	3-3
2:05 p.m.	"High Pressure Atomization and Thick Sprays" F. V. Bracco, Princeton University	3-11
2:25 p.m.	"Wall Effects on Combustion in an Engine" F. E. Fendell, TRW Systems	3-21
2:45 p.m.	"Diesel Engine Cylinder Heat Flux and Gas Analysis" G. L. Borman, University of Wisconsin-Madison	3-43
3:05 p.m.	Coffee Break	----
	Session 4: ARO Combustion Research	
3:35 p.m.	Chairman: E. Mularz, AVRADCOM	4-1
3:40 p.m.	"Ignition and Flame Propagation in Sprays" W. A. Sirignano and S. C. Yao, Carnegie-Mellon University	4-3
4:00 a.m.	"Mechanism of Combustion of Hydrocarbon/Alcohol Blends" K. Seshadri, University of California-San Diego	4-13
4:20 p.m.	"Acoustic Signature from Flames as a Combustion Diagnostic Tool" W. C. Strahle, Georgia Institute of Technology	4-21
4:40 p.m.	"Combustion and Microexplosions of Water/Oil Emulsions in High-Pressure Environments" C. K. Law, Northwestern University	4-31
6:00 p.m.	Bus transportation from SwRI to Menger Hotel	----

Time		Page No.
	Wednesday, 8 December 1982	
7:45 a.m.	Bus transportation from Menger Hotel to SwRI	----
	Session 5: Fuels/Engines Technology	
8:15 a.m.	Chairman: F. W. Schaekel, MERADCOM	5-1
8:20 a.m.	"ARO Basic Study of Fuel Storage Stability" F. R. Mayo and B. Y. Lan, SRI-International	5-3
8:40 a.m.	"AFLRL Basic Research on Fuel Storage Stability" G. H. Lee and L. L. Stavinoha, AFLRL/SwRI	5-7
9:00 a.m.	"AFLRL Fire-Resistant Diesel Fuel Mechanisms Basic Research" W. D. Weatherford, Jr. and D. W. Naegeli, AFLRL/SwRI	5-13
9:20 a.m.	"Synopses of Other Related Basic Research at AFLRL/SwRI" T. W. Ryan, III, John O Storment, Ed C. Owens, and Lee G. Dodge, SwRI	5-25
10:00 a.m.	Coffee Break	----
	Session 6: Discussion Groups	
10:30 a.m.	Relocate to Designated Conference Rooms	6-1
10:35 a.m.	Reciprocating Engines/Fuels Discussions Discussion Leader: S. S. Lestz, Penn State University	----
10:35 a.m.	Turbine Engines/Fuels Discussions Discussion Leader: A. M. Mellor, Drexel University	----
12:20 p.m.	Lunch Break	----
1:30 p.m.	Continuation of Discussion Groups	----
2:30 p.m.	Break	----
2:50 p.m.	Reports by Discussion Leaders	----
3:10 p.m.	Recapitulation D. M. Mann, ARO	----
3:30 p.m.	Transportation from SwRI to Airport or Menger Hotel	----

INTRODUCTION/OVERVIEW OF WORKSHOP

David M. Mann
Engineering Sciences Division
U. S. Army Research Office
Research Triangle Park, NC

This Engine/Fuels Workshop comes at a critical time. The Army is in the process of developing strategy for employment of its forces in the next century. Central to this strategy is rapid movement and high mobility of air and land components. Coupled with the projected fuel requirements of Army systems, increased mobility will bring staggering fuel logistics problems. These difficulties are being compounded by the predictable decline in fuel "quality" as non-conventional fuels come into use. Basic research can provide the directions for the new technologies needed to meet the Army's future mobility requirements.

The purpose of the title "Engine/Fuels Workshop" was to call attention to the fact that we are dealing with a coupled problem. Current, "well engineered" combustion systems deliver high combustion efficiency when operating at their design point on their design fuel. Most suffer serious degradation in other operating regimes or with other fuels. The challenge is to develop the understanding of the interactive fuel and combustion processes which will allow the broadest range of operation and fuel utilization. Additionally, the availability of reliable models of the combustion process will allow less hardware and test-intensive engine development and provide initial designs closer to optimum. Of course, the fundamental goal is not just combustion efficiency but rather energy efficiency, the conversion of fuel-stored energy into useful mechanical energy. In this respect, compound engines, for example the turbo-compound adiabatic diesel, provide promise for real efficiency gains but also provide challenges for combustion optimization.

At this workshop, researchers have been asked to describe their current work and to give their perspectives on the pressing issues in this area. The discussion sessions which follow these presentations will allow us to focus on the major issues and define critical research needs. Participants are encouraged to present both evolutionary and revolutionary thoughts as both are needed to meet the challenge.

Session 1
U. S. ARMY PROGRAMS

Chairman: S. J. Lestz
U. S. Army Fuels and Lubricants Research Laboratory
Southwest Research Institute
San Antonio, TX

U.S. ARMY MOBILITY FUELS R&D PROGRAM

BY
M. E. LEPERA

U.S. ARMY MOBILITY EQUIPMENT R&D COMMAND
FUELS AND LUBRICANTS DIVISION
ENERGY AND WATER RESOURCES LABORATORY

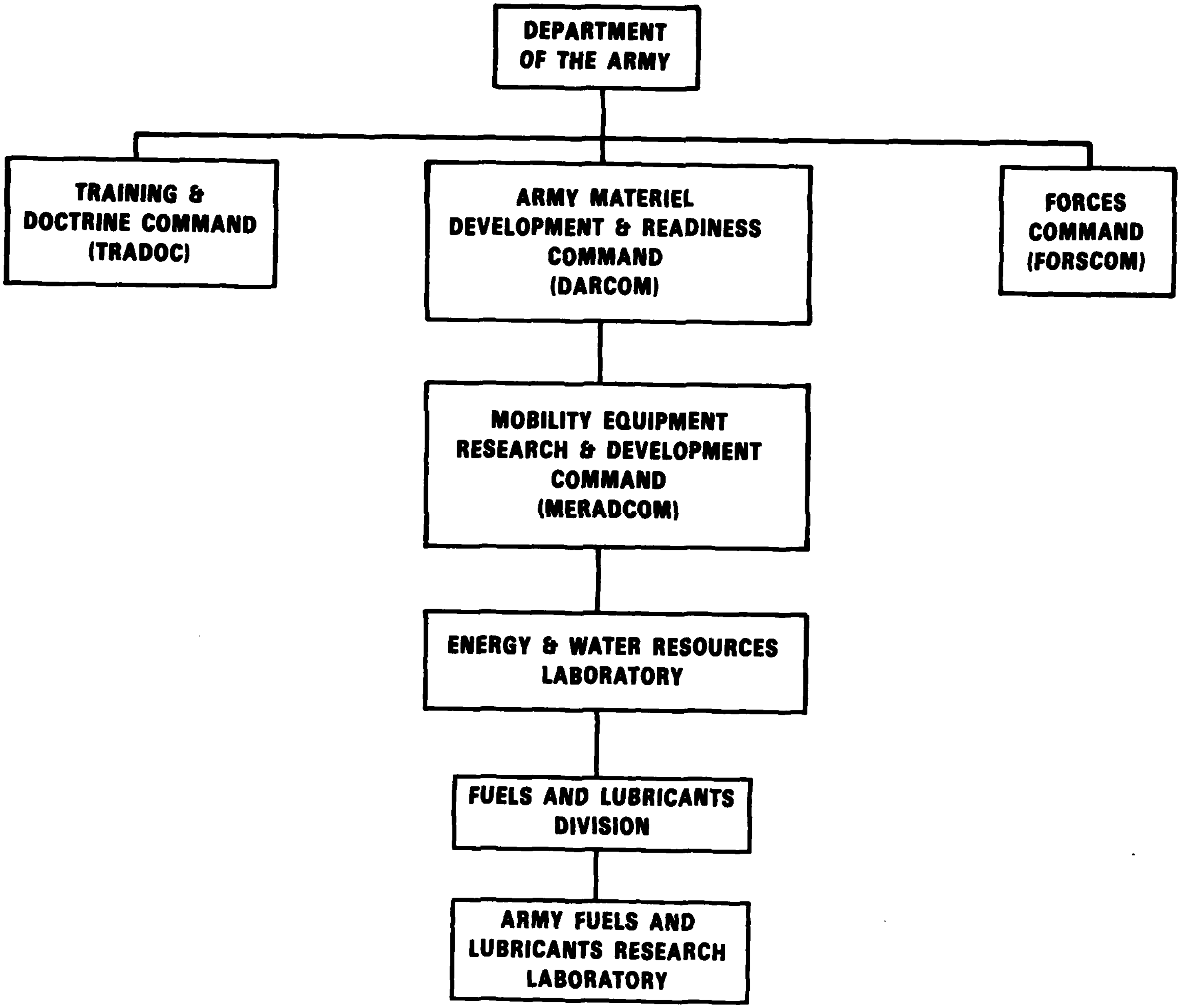
PRESENTED AT THE ARO/MERADCOM
ENGINE/FUELS WORKSHOP

7-8 DECEMBER 1982

U.S. ARMY
MOBILITY FUELS
R&D PROGRAM

U S ARMY MOBILITY EQUIPMENT
MERADCOM
RESEARCH & DEVELOPMENT COMMAND

FUELS & LUBRICANTS DIVISION
ENERGY & WATER RESOURCES LABORATORY
U.S. ARMY FUELS AND LUBRICANTS RESEARCH LABORATORY

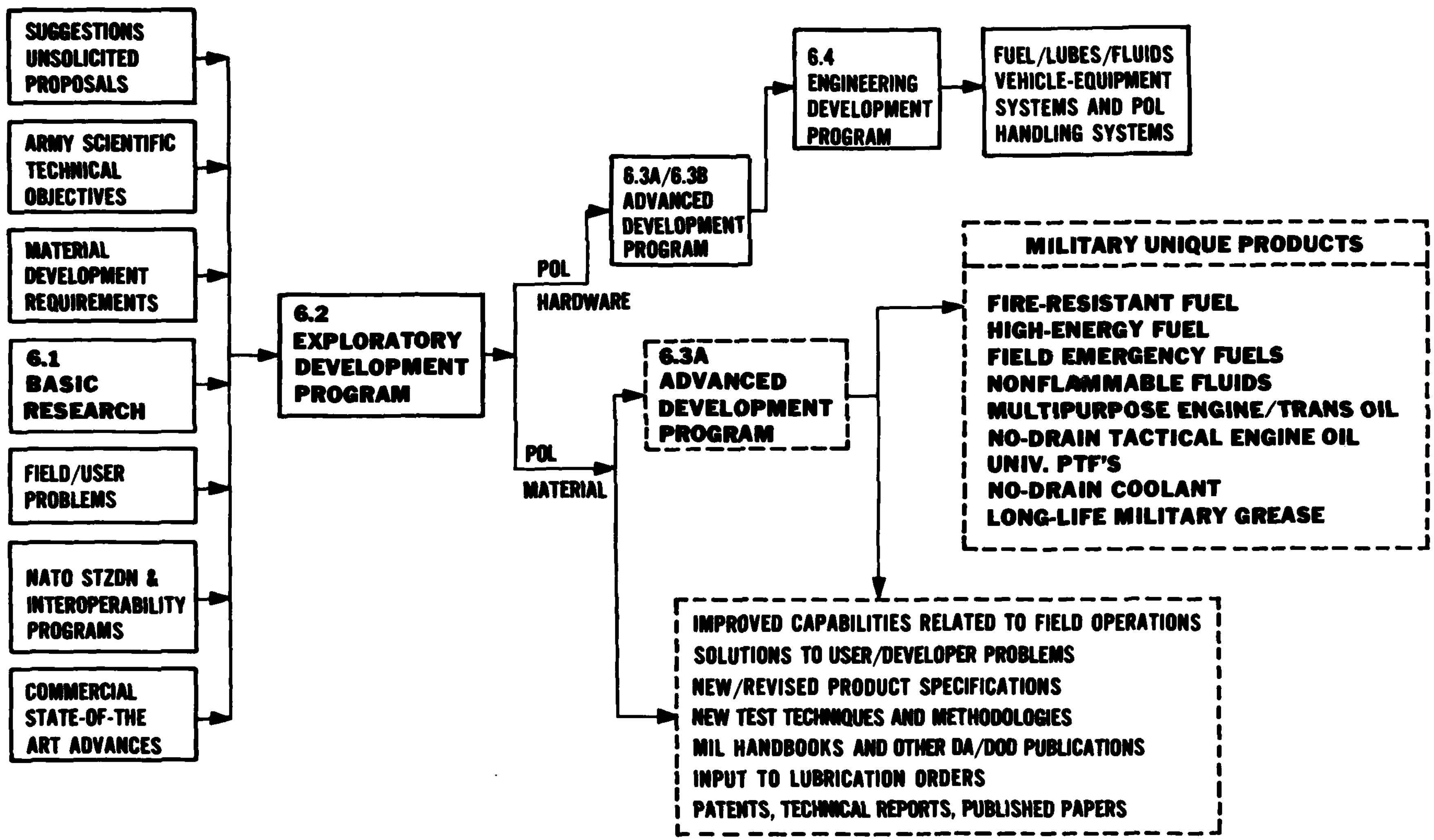

DEPARTMENT OF THE ARMY
TRAINING & DOCTRINE COMMAND (TRADOC)
ARMY MATERIEL DEVELOPMENT & READINESS COMMAND (DARCOM)
FORCES COMMAND (FORSCOM)
MOBILITY EQUIPMENT RESEARCH & DEVELOPMENT COMMAND (MERADCOM)
ENERGY & WATER RESOURCES LABORATORY
FUELS AND LUBRICANTS DIVISION
ARMY FUELS AND LUBRICANTS RESEARCH LABORATORY

FUELS AND LUBRICANTS

MAJOR THRUSTS

• ALTERNATIVE & SYNTHETIC FUELS	TO INCREASE AVAILABILITY OF MOBILITY FUELS FOR DOD UTILIZATION
• COMBAT MOBILITY FUELS	TO INCREASE VEHICLE/CREW SURVIVABILITY OF ARMORED EQUIPMENT
• LUBRICANTS FOR CONVENTIONAL & NON-CONVENTIONAL POWERTRAIN SYSTEMS	TO INSURE ADEQUACY AND AVAILABILITY OF MILITARY LUBRICANTS FOR CURRENT & ADVANCED ENGINE SYSTEMS
• CORROSION PREVENTATIVES	TO INCREASE OPERATIONAL READINESS OF VEHICLES & EQUIPMENT THROUGH REDUCTION IN MATERIEL DETERIORATION
• FUNCTIONAL FLUIDS	TO IMPROVE COMBAT EFFECTIVENESS THROUGH DEVELOPMENT OF NON-FLAMMABLE AND MULTI-FUNCTIONAL FLUIDS

F & L PROGRAM "ACQUISITION" PROCESS



ARMY FUELS/LUBRICANTS/FLUIDS RDT&E

PACING FACTORS

- ***IMPROVE SURVIVABILITY***
  - **FUEL/FLUIDS VULNERABILITY**
- ***IMPROVE COMBAT EFFECTIVENESS***
  - **INCREASE FUELS AVAILABILITY—USE OF ALTERNATIVES/SYNTHETICS**
- ***ELEVATE COMBAT READINESS***
  - **ELIMINATE FUEL DETERIORATION**
  - **DEVELOP LONG-LIFE/NO-DRAIN ENGINE/POWERTRAIN LUBRICANTS AND COOLANTS**
  - **DEVELOP COMMON/MULTIPURPOSE PRODUCTS**
  - **DEVELOP PRODUCTS TO IMPROVE RAM-D**
- ***NEW WEAPON/MOBILITY SYSTEMS* INTERFACE**

ARMY FUELS/LUBRICANTS/FLUIDS RDT&E

PROGRAM GOALS

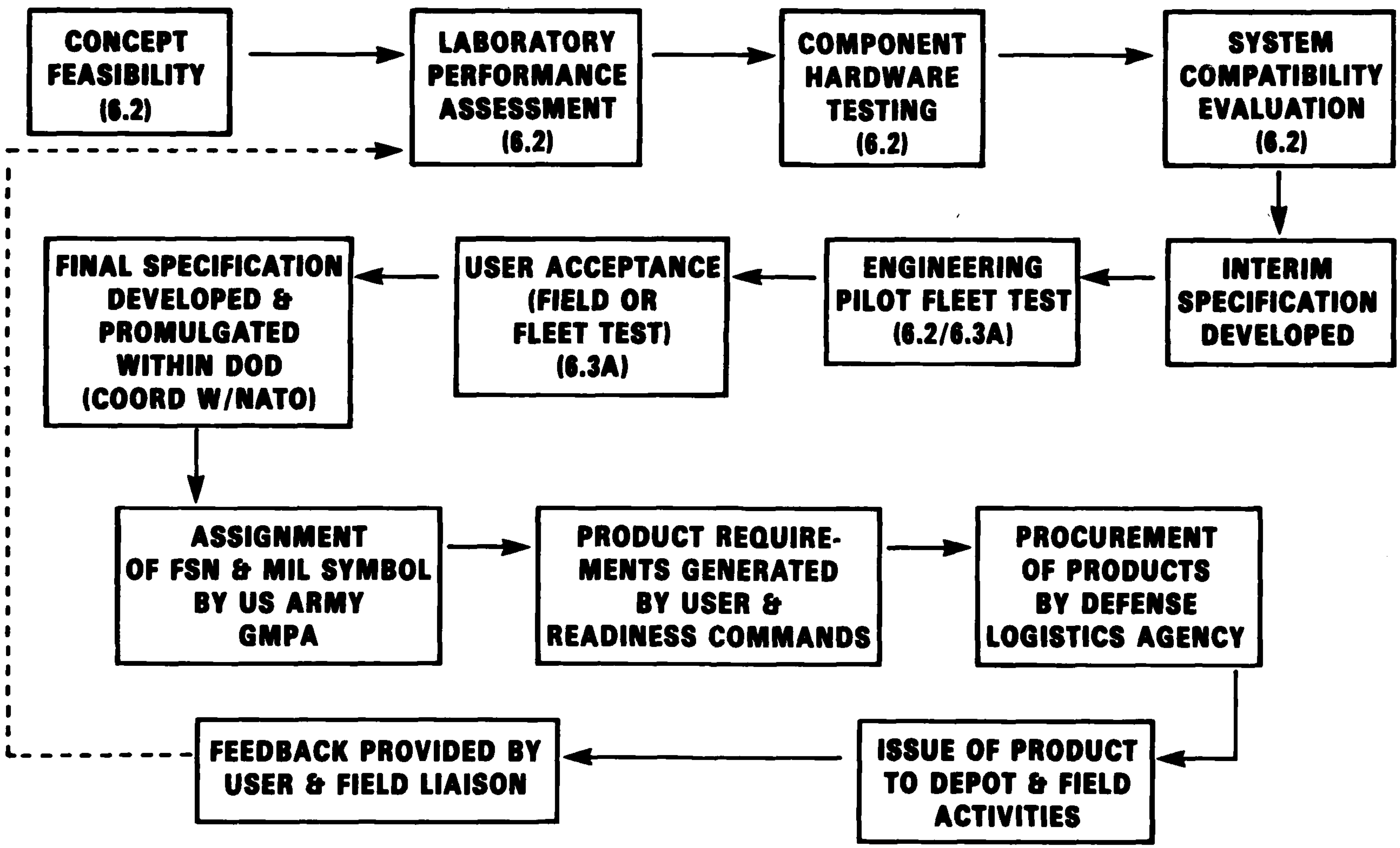
- ***REDUCED*** **FIRE HAZARD/VULNERABILITY DUE TO FUEL/FLUID FLAMMABILITY**
- ***INCREASED AVAILABILITY*** **OF** ***FUELS*** **THROUGH ALTERNATE/FIELD EMERGENCY FUELS, BROADENING SPECIFICATIONS, AND USE OF SYNTHETIC FUELS**
- ***RAPID MEANS*** **FOR DEFINING PERFORMANCE CHARACTERISTICS AND QUALITY OF PETROLEUM PRODUCTS**
- ***DEVELOPMENT*** **OF** ***LIFETIME*** **LUBRICANT AND COOLANT SYSTEMS**
- ***MINIMIZE*** **CORROSION/WEAR PROBLEMS AND IMPROVE RAM-D CHARACTERISTICS FOR ARMY SYSTEMS**
- ***ELIMINATE*** **USE OF PROPRIETARY PRODUCTS BY SPECIFICATION DEVELOPMENT/CONSOLIDATION**

FUELS/LUBRICANTS/FLUIDS RDT&E

TECHNICAL EFFORTS

- HYDROCARBON FUELS AND COMBUSTION AND FUEL DECONTAMINATION
- LUBRICANTS FRICTION AND WEAR
- POWER TRANSMISSION FLUIDS AND HYDRAULIC FLUIDS
- CORROSION PREVENTIVES AND SPECIALTY CMPDS

TECHNOLOGY ROAD MAP FOR FUELS & LUBRICANTS PRODUCTS



UNIQUE REQUIREMENTS FOR ARMY MOBILITY FUELS

- SURVIVABILITY: REDUCE/ELIMINATE FUEL FIRE HAZARDS
- COMMONALITY OF FUELS
  - NATO STANDARDIZATION
  - INTEROPERABILITY
- ENHANCED STORAGE STABILITY
- MULTIPURPOSE USE (LOW VS HIGH AMBIENT TEMPERATURES)
- UNIQUE SPECIFIC FUEL INHIBITORS REQUIRED
- INCREASED UTILIZATION EFFICIENCY AND HIGH ENERGY POTENTIAL DESIRED
- EMERGENCY FUEL APPLICATIONS

<u>MOBILITY FUEL RELATED PROBLEMS IMPACTING DOD READINESS</u>

- VAPOR-LOCK PROBLEMS (HOT RESTART & ALTITUDE STALLING) IDENTIFIED WITH BLACK HAWK (UH-60A) OPERATING IN AMBIENT TEMPERATURES ABOVE 95°F
- STARTING PROBLEMS IDENTIFIED WITH M-1 TANKS OPERATING IN GERMANY BECAUSE OF FUEL WAXING
- ENGINE FAILURE PROBLEMS (MASSIVE INJECTOR SEIZURES) WITH USN SHIP SYSTEMS DUE TO UNSTABLE DIESEL FUEL
- EXCESSIVE FILTER PLUGGING OCCURRING WITH ARMORED VEHICLES OPERATING AT FORTS HOOD, IRWIN, & BLISS BECAUSE OF UNSTABLE DIESEL FUEL

NOTE: ABOVE PROBLEMS ALL OCCURRED WITH FUELS <u>THAT</u> <u>MET</u> <u>THEIR</u> SPECIFICATION REQUIREMENTS

ARMY MOBILITY FUELS PROGRAM
MAJOR THRUSTS

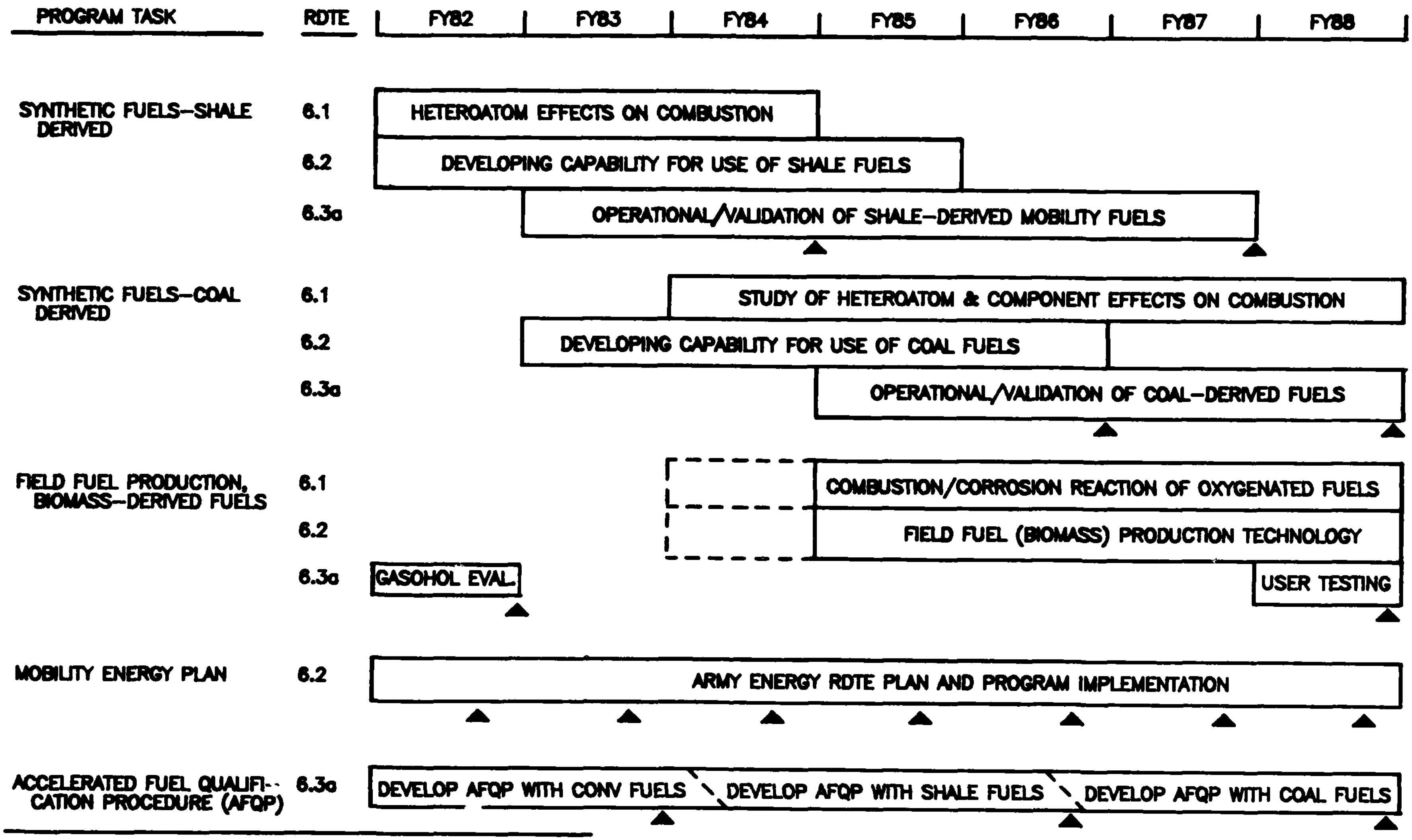
6.1 BASIC RESEARCH

- FIRE-RESISTANT FUEL MECHANISMS (OPTIMIZATION PURPOSES)
- HETEROATOM/COMPOSITION EFFECTS ON DEPOSITS/ WEAR
- FUEL DETERIORATION ADDITIVE INHIBITION MECHANISMS

6.2/6.3A DEVELOPMENT

- FIRE-RESISTANT FUEL FOR WORLDWIDE USE
- ADDITIVE STABILIZER TO REDUCE DIESEL FUEL DETERIORATION
- METHODS FOR MONITORING FUEL QUALITY IN FIELD ENVIRONMENTS
- CAPABILITY FOR USING SYNTHETIC/ALTERNATIVE FUELS
- FIELD-EMERGENCY FUELS CAPABILITY

ALTERNATE AND SYNTHETIC FUELS



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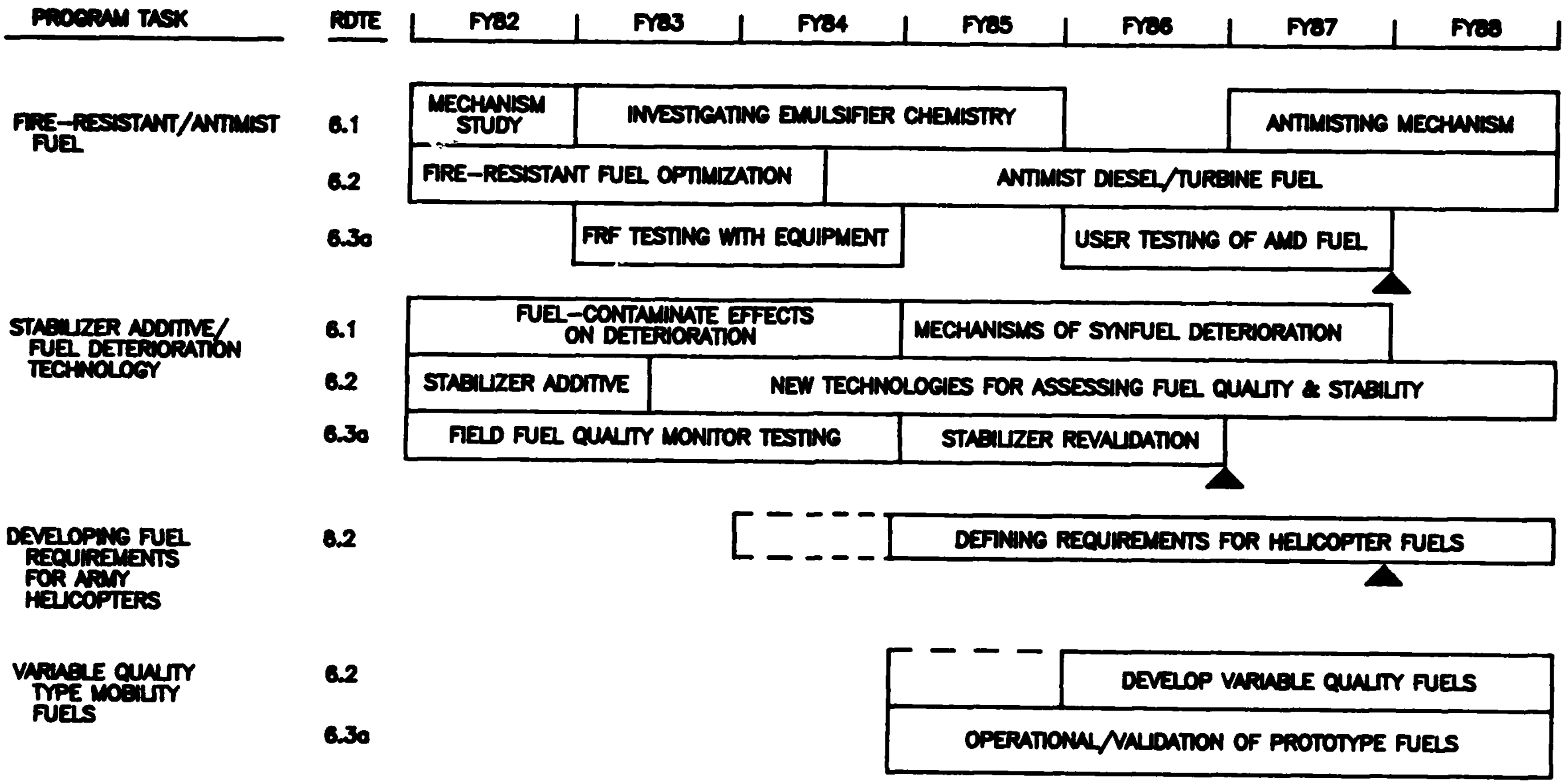
- - - DESIGNATION INDICATES UNFUNDED EFFORT

COMBAT MOBILITY FUELS



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- - - DESIGNATION INDICATES UNFUNDED EFFORT

ARMY FUEL STABILITY/ DETERIORATION INTERESTS

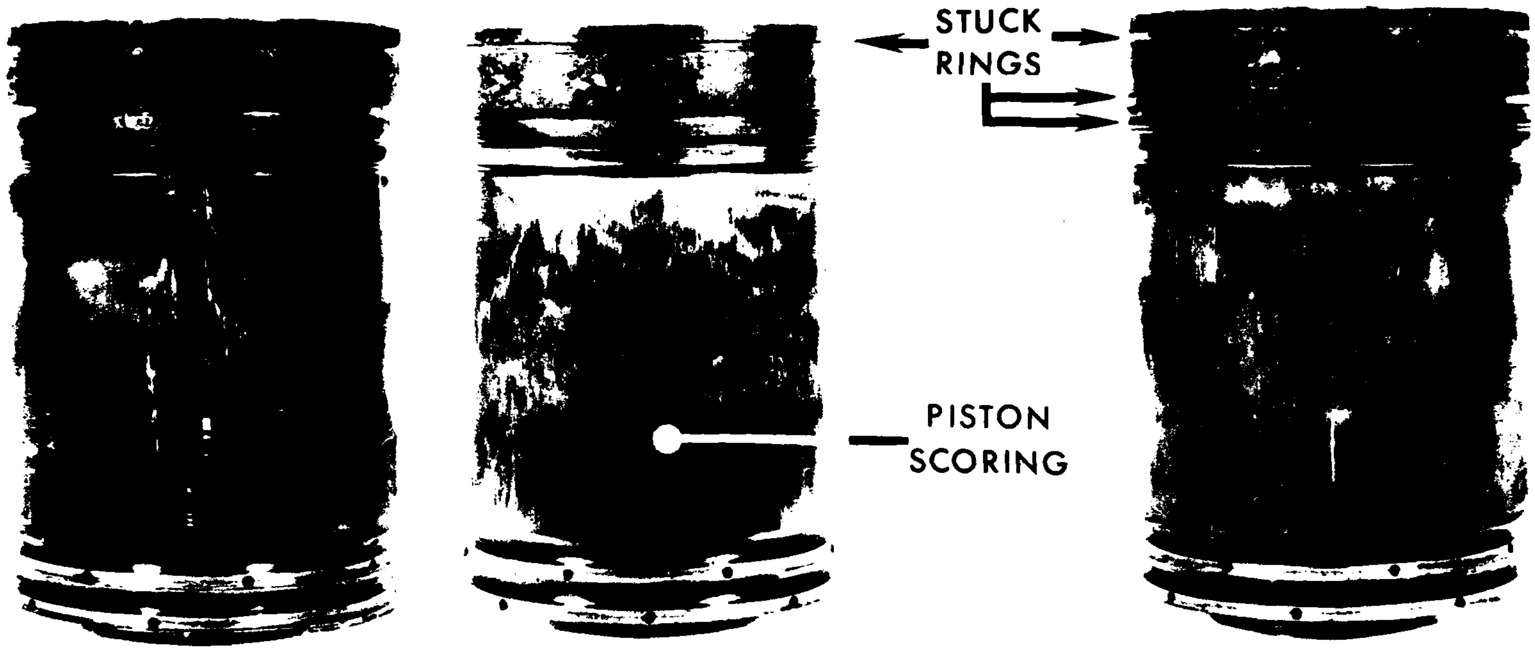
FACTORS AFFECTING FUEL DETERIORATION

- CONTAMINANTS
- ENVIRONMENT
- OPERATIONAL FACTORS

CURRENT ARMY RDTE EFFORTS

- INVESTIGATION OF PROCESS & ENVIRONMENTAL INFLUENCE
- DEVELOP ADDITIVE STABILIZER PACKAGE
- DEVELOP FIELD TEST KIT TO DEFINE IN-SERVICE CONDITION
- PROVIDE LIAISON TO USER/CONDUCT FIELD EVALUATIONS

DIESEL FUEL SULFUR CONTENT AND THE ARMY TWO-CYCLE DIESEL ENGINE PROBLEM



ACCEPTABLE
VVF-800B-CONUS
0.50% S MAX

UNACCEPTABLE
EXAMPLES FOR HIGH SULFUR FUELS

ENGINE MFR RQMTS:
- SULFUR SHOULD BE LESS THAN 0.50%

MIL SPEC LIMITS:
- VVF-800B OCONUS/F-54–0.70% S MAX
- MIL-F-16884 USN–1.00% S MAX

TYPICAL OCONUS SULFUR RANGE:
- 0.80-1.30%

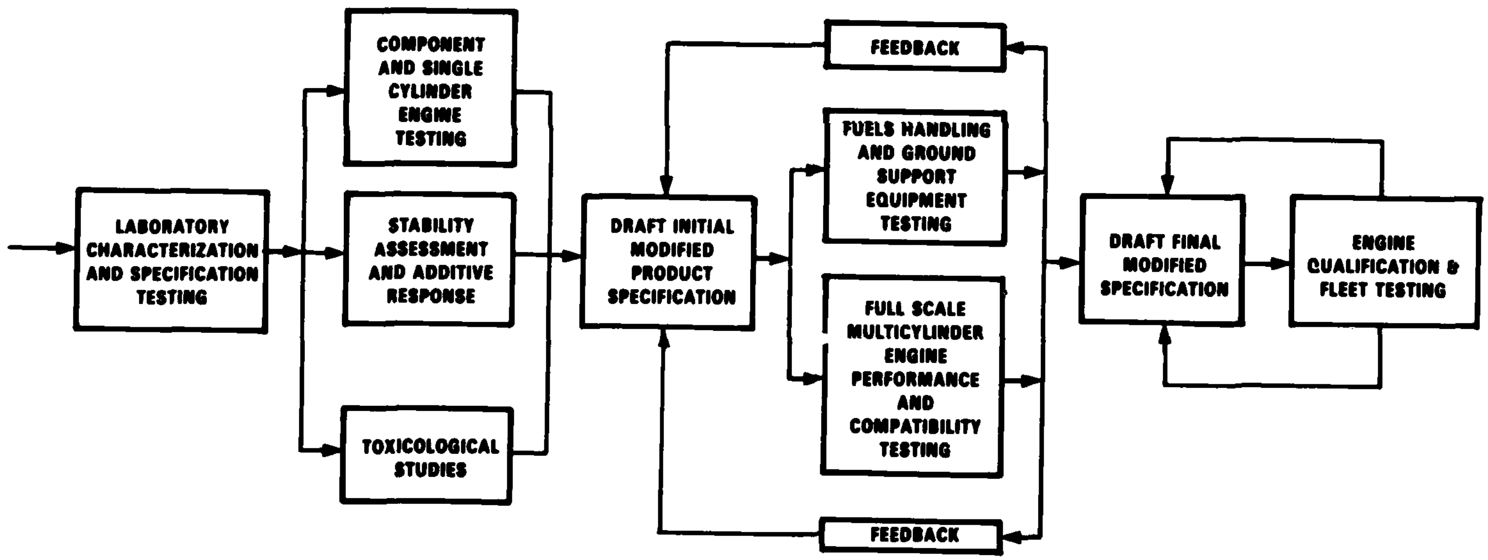
VEHICLES AFFECTED:
- SELF-PROPELLED ARTILLERY FAMILY
- M113, FAMILY APC
- M578, RECOVERY VEHICLE
- M551, SHERIDAN
- M561, GAMMA GOAT
- HET-70 AND OTHER CARGO CARRIERS

U.S. ARMY'S ALTERNATIVE & SYNTHETIC FUELS PROGRAM

MAJOR EFFORTS

- **DEVELOP CAPABILITY FOR USING SYNTHETIC AND ALTERNATIVE FUELS**
- **DEVELOP NEW, ACCELERATED FUEL-ENGINE QUALIFICATION PROCEDURE METHODOLOGY**
- **CONDUCT GASOHOL EVALUATION AND ISSUE SPECIFICATION**

PROCESS FOR EVALUATING NEW/SYNTHETIC FUELS



PETROLEUM SUPPLY-DEMAND ASSESSMENT

TEMPORARY GLUT OF WORLD CRUDE RESULT OF -

- 1979-80 INCREASES IN CRUDE PRICES HAVE SLOWLY REDUCED OVERALL DEMAND, MOTIVATION FOR GREATER CONSERVATION
- INCREASED CRUDE PRODUCTION BY SAUDIA ARABIA AT ONSET OF IRAN-IRAQ CONFLICT
- WORLDWIDE RECESSION HAS DAMPENED DEMAND
- DECONTROL CAUSED INCREASED CONUS CRUDE PRODUCTION

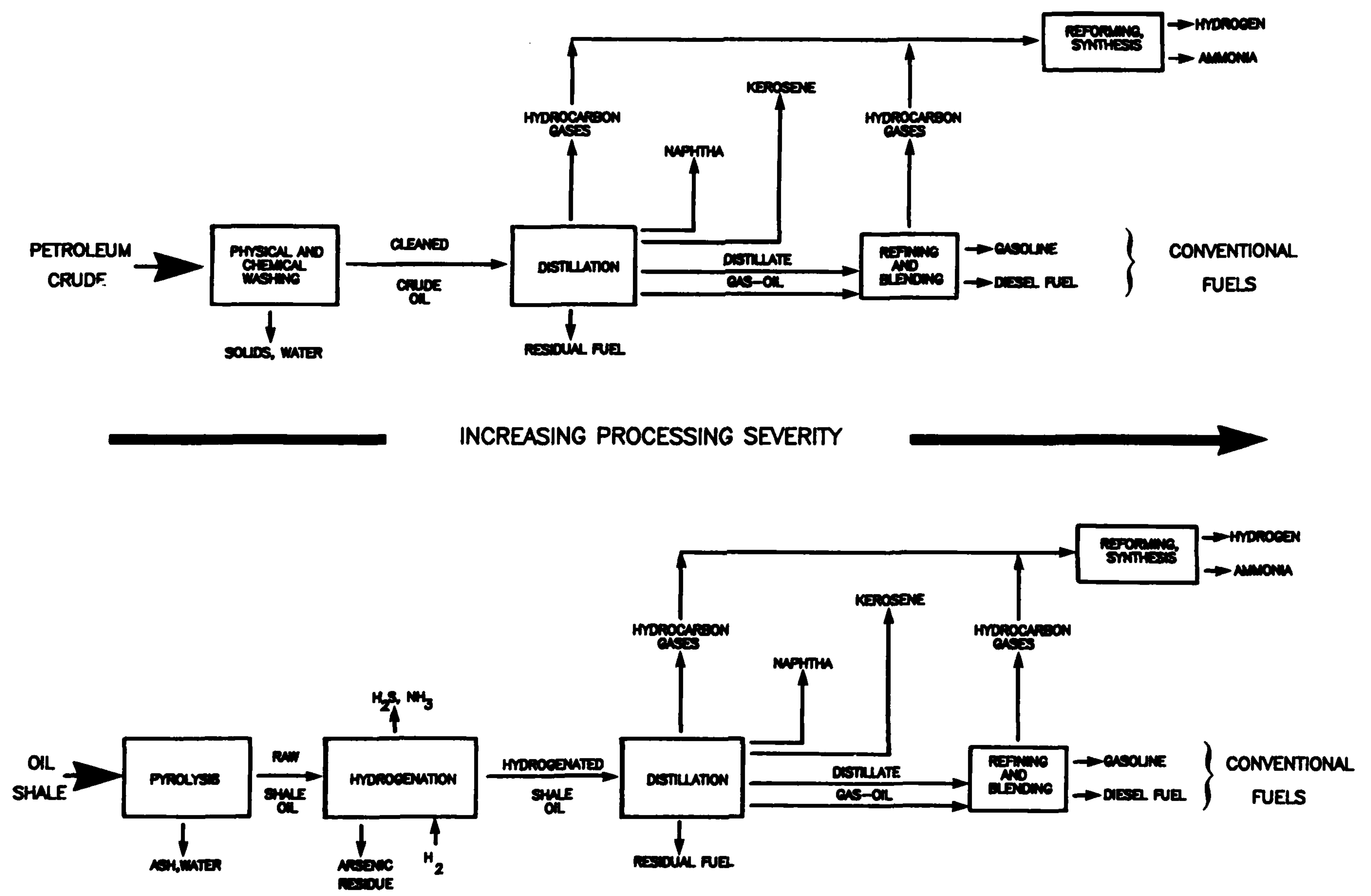
MAJOR DISRUPTION IN MIDDLE EAST CRUDE PRODUCTION DURING DECADE HIGHLY POSSIBLE. RESULTANT PROBLEMS COMPOUNDED BECAUSE

- AGREEMENTS EXISTING WITHIN INTERNATIONAL ENERGY AGENCY COMPOSED OF 21 NATIONS (US COMMITTED TO SUPPORT OTHER COUNTRIES DURING EMBARGO)
- RECENT NATIONALIZATION OF WORLD CRUDE SUPPLIES
  - INTERNATIONAL COMPANIES CURRENTLY HANDLE ONLY 50% OF WORLD CRUDE. DURING PREVIOUS EMBARGO, THEY HANLED 90%
- RESPONSE TIME FOR INCORPORATING SOLUTIONS WILL BE LONGER

DOD'S SOLUTIONS FOR MOBILITY ENERGY SELF-SUFFICIENCY

- REDUCE ENERGY CONSUMPTION IN MOBILITY OPERATIONS BY 10% BY FY85 AND ZERO GROWTH FROM THEN TO YEAR 2000
- SECURE DOMESTIC CRUDE SOURCES (ROYALTY OIL FROM OCS, NPR & ACCESS TO SPR)
- REDUCE DEPENDANCE ON NON-RENEWABLE SOURCE FUELS BY DEVELOPING CAPABILITY FOR USING SYNTHETIC FUELS
- US SYNFUELS INDUSTRY NEEDED TO -
  - SERVE WARNING TO OPEC WHEN CRUDE PRICES BECOME UNREALISTIC
  - ESTABLISH BASIS FOR PROVIDING US WITH SOME MEASURE OF ENERGY SECURITY
  - SOURCE OF SYNFUELS NEEDED FOR DOD IN PEACETIME TO SUPPORT TRAINING & REAINDESS REQUIREMENTS AND ELIMINATE COMPETITION FOR FUELS WITH CIVILIAN USERS
- FUNDING FOR MOBILITY ENERGY CANNOT VASCILATE IF OBJECTIVES ARE TO BE MET

FUELS OBTAINABLE FROM PETROLEUM AND SHALE OIL



DEVELOP ACCELERATED FUEL QUALIFICATION/SPECIFICATION PROCEDURES

WHY?

- TIME FOR CERTIFYING/VALIDATING ENGINE SYSTEMS ON NEW FUELS OR FUELS ON NEW SYSTEMS TOO LENGTHY
- COSTS FOR CONDUCTING TESTS, LABOR, HARDWARE, & FUEL COSTS
- FUEL CONSERVATION
- NO FLEXIBILITY EXISTS FOR "SHORT-CUTS," I.E., CONVERSION OF JP-4 TO JP-8
- REFINERY FEEDSTOCKS & PRODUCT SLATES ANTICIPATED TO BECOME MORE VARIABLE

ENGINE SYSTEMS USED IN ARMY GROUND & AVIATION EQUIPMENT

SPARK-IGNITION

TWO-CYCLE	AIR-COOLED	NORMALLY-ASPIRATED
TWO-CYCLE	LIQUID-COOLED	NORMALLY-ASPIRATED (MARINE APPLICATION)
FOUR-CYCLE	LIQUID-COOLED	NORMALLY-ASPIRATED
FOUR-CYCLE	AIR-COOLED	NORMALLY-ASPIRATED AND TURBOCHARGED (MARINE AND AVIATION APPLICATIONS)

COMPRESSION-IGNITION

TWO-CYCLE	LIQUID-COOLED	NORMALLY-ASPIRATED AND TURBOCHARGED
FOUR-CYCLE	LIQUID-COOLED	NORMALLY-ASPIRATED, TURBOCHARGED AND MULTIFUEL
FOUR-CYCLE	AIR-COOLED	TURBOCHARGED

GAS TURBINE

GAS TURBINE	TURBO-SHAFT/ TURBO-PROP	AVIATION AND GROUND

LISTING OF ARMY FUEL-CONSUMING MOBILITY AND COMBAT SUPPORT EQUIPMENT

EQUIPMENT CATEGORY	NO. OF INDIVIDUAL NSN LISTING	NO. OF DISTINCTIVE ENGINE TYPES
COMBAT TRACKED VEHICLES	59	25
TACTICAL WHEELED VEHICLES	165	
FIXED WING AIRCRAFT	21	10
ROTARY WING AIRCRAFT	22	
GENERATOR SETS	168	56
POWER PLANTS	16	2
CONSTRUCTION EQUIPMENT	210	74
AMPHIBIOUS & BOARD EQUIPMENT	34	23
MATERIAL HANDLING EQUIPMENT	78	17
OTHER VEHICLES	42	17
HEATING EQUIPMENT	21	3
STATIONARY EQUIPMENT, MISC.	258	36

ENGINE TYPES & FUEL CONSUMPTION RATES

ENGINE	TYPE	VEHICLE/AIRCRAFT	RATE OF FUEL CONSUMPTION		TOTAL FUEL QUANTITY REQUIRED		
			MPG	GPH	GAL.	DRUMS	BBLS
HERCULES, L141	4 CYL, 4 CYCLE S.I.	TRUCK, UTILITY, 1/4 T, M-151	16	4	1800	33	43
CONTINENTAL, LDT-465	6 CYL, 4 CYCLE C.I. (MAN SYSTEM)	TRUCK CARGO, 2-1/2 T, M34/M35	5	10	4500	83	107
CUMMINS, NHC 250	6 CYL, 4 CYCLE C.I.	TRUCK, CARGO 5 T, M 813	4.2	10.5	4725	88	113
DETROIT DIESEL 6V-53T	6 CYL, 2 CYCLE C.I.	ARMORED ASSAULT VEHICLE, M-551	1.9	15	6750	125	161
CONTINENTAL, AVDS-1790-2C	12 CYL, 4 CYCLE C.I., AIR-COOLED	MAIN BATTLE TANK, M-60/M-48	0.7	40	18,000	333	429
AVCO-LYCOMING AGT-1500	GAS TURBINE, RECUPERATED	XM-1 TANK SYSTEM	0.54	46.3	46,300	857	1102
GENERAL ELECTRIC T-700	GAS TURBINE, TURBOSHAFT	UTILITY HELICOPTER, UH-60A	--	81.7*	81,700	1513	1945

* RATED AT 1000 HP

NOTE: FUEL QUANTITIES REFLECT RQMTS FOR SINGLE TESTS, 450 HR FOR C.I./S.I. ENGINES & 1000 HR FOR GAS TURBINE ENGINES

DISTRIBUTION OF ARMY GROUND EQUIPMENT FUEL NEEDS

EQUIPMENT TYPE	FUEL(S) UTILIZED
• COMBAT VEHICLES (TANKS, SP ARTILLERY, APC'S)	DIESEL
• TACTICAL VEHICLES (TRUCKS, REFUELERS)	DIESEL & MOGAS
• ENGINEER/CONSTRUCTION	DIESEL
• PERSONNEL SUPPORT (MHE, KITCHENS, HEATERS, AIR COND.)	DIESEL & MOGAS
• MOBILE POWER GENERATION	DIESEL & MOGAS
• ADMINISTRATIVE VEHICLES (CML SDNS, P/U TRKS, WGNS)	MOGAS

MOBILITY FUEL-CONSUMING SOLDIER-SUPPORT EQUIPMENT

STATIONARY EQUIP

AIR COMPRESSORS	ELECTRIC SYS	REFRIGERATION UNITS
FIELD BATH UNITS	LAUNDRY UNIT	SPRAYER UNITS
CLOTHING REPAIR SYS	LUBRICANT SERVICING SYS	WELDING MACHINE SYS
DECONTAMINATION SYS	PUMPS	DISTRIBUTOR WATER SYS

CONSTRUCTION

EARTH AUGER	DRIERS	ASPHALT MIXERS	SWEEPERS
CONVEYOR BELT SYS	MACHINE DRILLERS	CONSTRUCTION MIXERS	WHEELED TRACTORS
SHOVEL CRANES	PILE HAMMERS	PAVING EQUIP	
WHEEL CRANES	KETTLES	ROLLERS	

POWER GENERATION

HEATING EQUIP

MATERIALS-HANDLING EQUIP

- CRANE TRUCKS
- FORK-LIFT TRUCKS

DEVELOP ACCELERATED FUEL QUALIFICATION/SPECIFICATION PROCEDURES

HOW?

- **DEVELOP NEW TECHNIQUES FOR CRITICAL FUEL PROPERTIES/CHARACTERISTICS (I.E., HYDROCARBON DISTRIBUTION, LUBRICITY, NONHYDROCARBON CONSTITUENTS, ETC.)**
- **DEVELOP ACCELERATED COMPONENT & ENGINE TESTING & EVALUATION PROCEDURES**
- **DEVELOP REFEREE-TYPE FUELS TO MAXIMIZE "WORST CASE" CONDITION AND ACCELERATE TESTING INTERVAL**
- **INCORPORATE ABOVE WITH COMPUTER MODELING TECHNIQUES INTO ACCELERATED QUALIFICATION METHODOLOGY**
- **VALIDATE DEVELOPED SYSTEMS WITH FULL-SCALE DURABILITY TEST PROGRAMS**

U.S. ARMY'S TWO-YEAR GASOHOL PROGRAM

OBJECTIVE:

- TO DETERMINE SUITABILITY FOR USING GASOHOL IN ALL GASOLINE-CONSUMING MILITARY EQUIPMENT

GOAL:

- ISSUANCE OF GASOHOL SPECIFICATION FOR TACTICAL EQUIPMENT (FY82)

MAJOR PHASES:

- LABORATORY CHARACTERIZATION & COMPATIBILITY TESTING
- ENGINE AND GROUND SUPPORT EQUIPMENT TESTING
- FLEET TESTING AT FOUR ARMY BASES

ARMY USE OF GASOHOL

AREAS OF MAJOR CONCERN

- MATERIAL COMPATIBILITY PROBLEMS WITH ELASTOMERS, FILTER MEDIA, PLASTICS
- PERFORMANCE IN MILITARY DESIGNED ENGINE SYSTEMS
- STORAGE INSTABILITY DUE TO VEHICLE USE, LONG RESIDENCE TIMES, & WATER CONTAMINATION
- PHASE SEPARATION
- INCREASED SOLVENCY CREATING PARTICULATE CONTAMINATION PROBLEMS
- MARGINAL LUBRICATION UNDER INTERMITTENT OPERATION
- FIELD MIXING PROBLEMS
- VAPOR RECOVERY REQUIREMENTS

UTILIZATION OF METHANOL IN ARMY EQUIPMENT

OBJECTIVE: DETERMINE POTENTIAL APPLICATION OF METHANOL TO AUGMENT MOBILITY FUEL REQUIREMENTS FOR SOLDIER, GROUND SUPPORT, & TACTICAL EQUIPMENT (PROGRAM ASSUMES METHANOL TO BECOME AVAILABLE IN BULK DURING LATE 1980s).

APPROACH: DEVELOP NECESSARY TECHNOLOGY FOR DEMONSTRATING USE OF METHANOL IN SELECTED ADMINISTRATIVE & TACTICAL GROUND EQUIPMENT

PROGRAM TO ADDRESS USE OF METHANOL AS

- SUBSTITUTE/ALTERNATIVE FUEL
- FUEL EXTENDER FOR GROUND MOBILITY FUELS

UTILIZATION OF METHANOL IN ARMY EQUIPMENT

APPROACH CONT'D)

AS SUBSTITUTE/ALTERNATIVE FUEL

- WHAT SYSTEMS CAN NOW ACCOMODATE METHANOL (NO CHANGES)
- WHAT SYSTEMS COULD ACCOMODATE METHANOL WITH MINIMAL RETROFIT (I.E., CHANGING FUEL SYSTEM MAT'LS, NO MAJOR ENGINE/FUEL DELIVERY SYSTEM RE-DESIGN)
- WHAT SYSTEMS COULD NOT ACCOMODATE METHANOL WITHOUT UNDERGOING MAJOR REDESIGN (I.E., CONVERSION NOT PRACTICAL)

AS FUEL EXTENDER FOR GROUND MOBILITY

FUELS

- USE IN AUTOMOTIVE GASOLINES
- USE IN DIESEL FUELS

METHANOL UTILIZATION PROGRAM

ASSESSMENT OF GROUND TACTICAL & ADMINISTRATIVE EQUIPMENT INVENTORIES

- DIRECT UTILIZATION (METHANOL TO DISPLACE GASOLINE/GASOHOL)
  - WITHOUT ANY MINOR SYSTEM CHANGES
  - WITH MINOR SYSTEM CHANGES
- INDIRECT UTILIZATION (METHANOL FOR BLENDING WITH MOGAS)
- INDIRECT UTILIZATION (METHANOL FOR BLENDING WITH DIESEL)

LABORATORY CHARACTERIZATION & COMPATIBILITY OF METHANOL, METHANOL-GASOLINE, AND METHANOL-DIESEL BLENDS

ENGINE & SYSTEMS TESTING

- METHANOL
- METHANOL-GASOLINE MIXTURES
- METHANOL-DIESEL FUEL MIXTURES

FUEL DISPENSING EQUIPMENT EVALUATIONS & TRANSPORTATION METHODS ASSESSMENT

CONTROLLED VEHICLE & EQUIPMENT USER TESTING

- METHANOL
- METHANOL-GASOLINE MIXTURES
- METHANOL-DIESEL FUEL MIXTURES

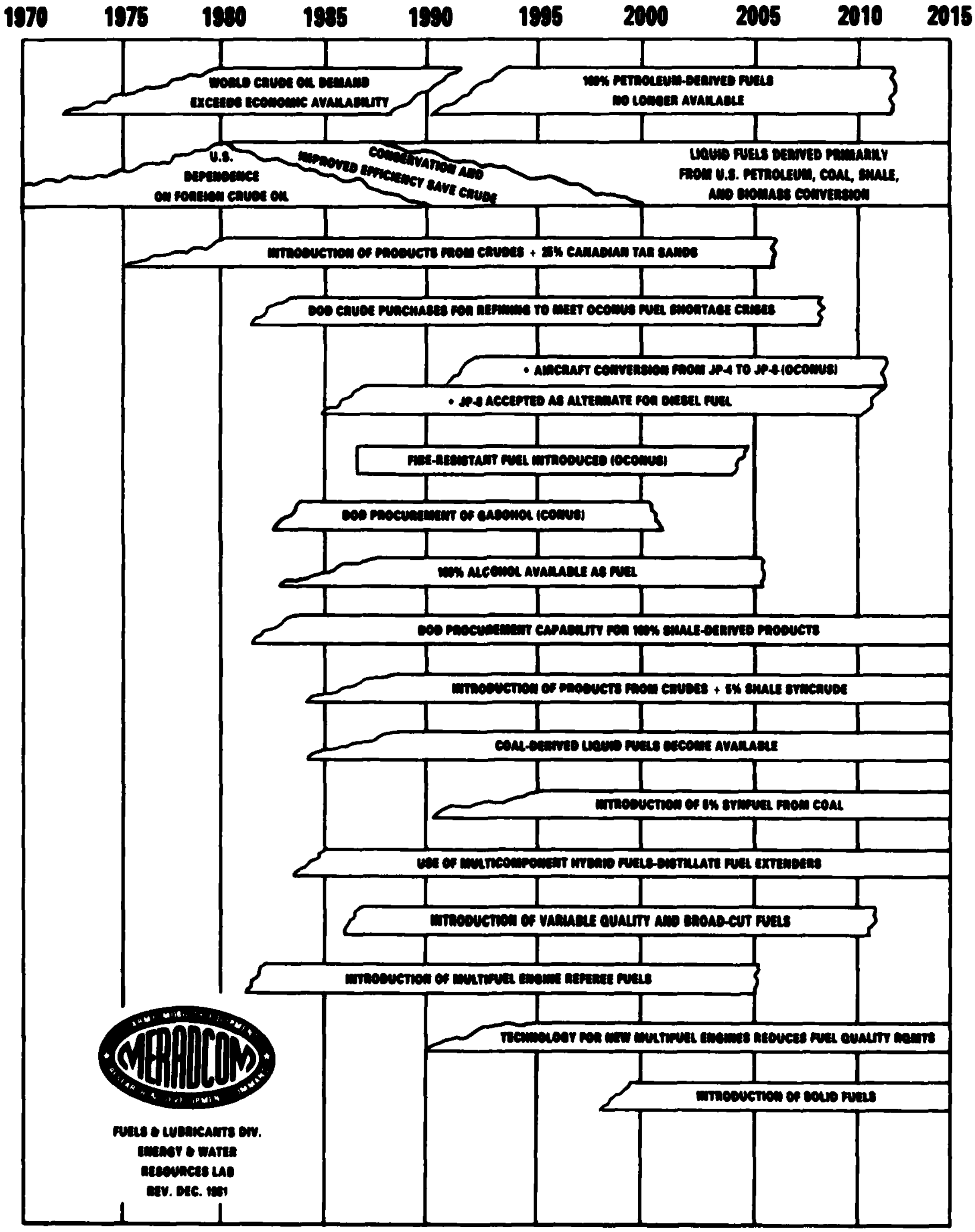
ARMY FUELS RDT&E PROGRAMS RELATED TO FUTURE FUELS AVAILABILITY

- BROAD BASE "CITE" FUELS DEVELOPMENT—1964
- AMMONIA FUEL (MOBILE ENERGY DEPOT)—1966
- ARMY ENERGY R&D PLAN—1971-73
- UNIVERSAL FUEL STUDIES/BROADENED DIESEL FUEL SPECIFICATIONS—1973-76
- EVALUATION OF USN COED FUEL BYPRODUCTS AND TAR SAND KEROSENE—1973-74
- ASSESSMENT OF H_2 AS VEHICLE FUEL—1974

ARMY FUELS RDT&E PROGRAMS RELATED TO FUTURE FUELS AVAILABILITY (CONT'D)

- CRUDE OIL CHARACTERISTICS PROGRAM AND DIRECT USE OF CRUDE OIL IN ARMY ENGINES AS EMERGENCY FUEL—1975-77
- EVALUATION OF PARAHO I AND PARAHO II SHALE FUELS—1975-80
- COOPERATIVE DOE/BETC-ARMY, SYNTHETIC FUELS STABILITY PROGRAM—1976-78
- COOPERATIVE DOE/TP-ARMY, ALCOHOL FUELS/LUBRICANTS REQUIREMENT—1976-PRESENT
- COOPERATIVE DOE/ARMY STRATEGIC PETROLEUM RESERVE CRUDE/PRODUCT STORAGE—1978-79
- ARMY MOBILITY FUELS SCENARIO—1978-PRESENT
- DEVELOPMENT OF ARMY MOBILITY ENERGY R&D PLAN—1980-PRESENT

ARMY MOBILITY FUELS SCENARIO



Engine Research, Development, and Acquisition Strategy for U.S. Army Ground Vehicles*

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and Richard Munt
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THE US ARMY CONDUCTS RESEARCH, Development & Acquisition programs on a wide variety of tactical and combat vehicles types. The spectrum of possible engines for use in these vehicles is very broad (Figure 1). Available resources for the research and development (R&D) of candidate engines, however, are far more limited and, further, not all of the possibilities are equally promising at any given time. Consequently, there is need for a management strategy by which the US Army Tank-Automotive Command (TACOM) can more effectively direct its R&D resources to those programs which will provide the greatest benefit to the overall effectiveness of the Department of Defense (DOD).

Faced with this challenge, TACOM has

ABSTRACT

The US Army conducts Research, Development & Acquisition programs on a wide variety of tactical and combat vehicle types. Available resources for the research and development (R&D) of candidate engines, however, are far more limited. Consequently, there is need for a management strategy by which the US Army Tank-Automotive Command (TACOM) can more effectively direct the limited Department of Defense (DOD) R&D resources to those programs which will provide the greatest benefit to the overall effectiveness of the DOD.

In response to this need, TACOM has evolved an engine R&D two-fold strategy. The first part of the strategy is the limitation of TACOM's R&D efforts to that range of engines wherein there are no cost-effective commercially available engine options. The second part of the strategy is the development of an objective, quantifiable methodology which integrates the highest priority goals into an overall evaluation of the cost/combat (or operational) effectiveness of candidate engines.

The methodology exploits the historic major goals of the R&D program which are reviewed in detail. This methodology will be further developed and considered as an evaluation screening tool to determine objectively the most promising engine alternatives warranting further development, test and evaluation as well as to determine the relative significance of the various R&D goals and their specific targets.

*Manuscript submitted to SAE for publication.

ENGINE CANDIDATES

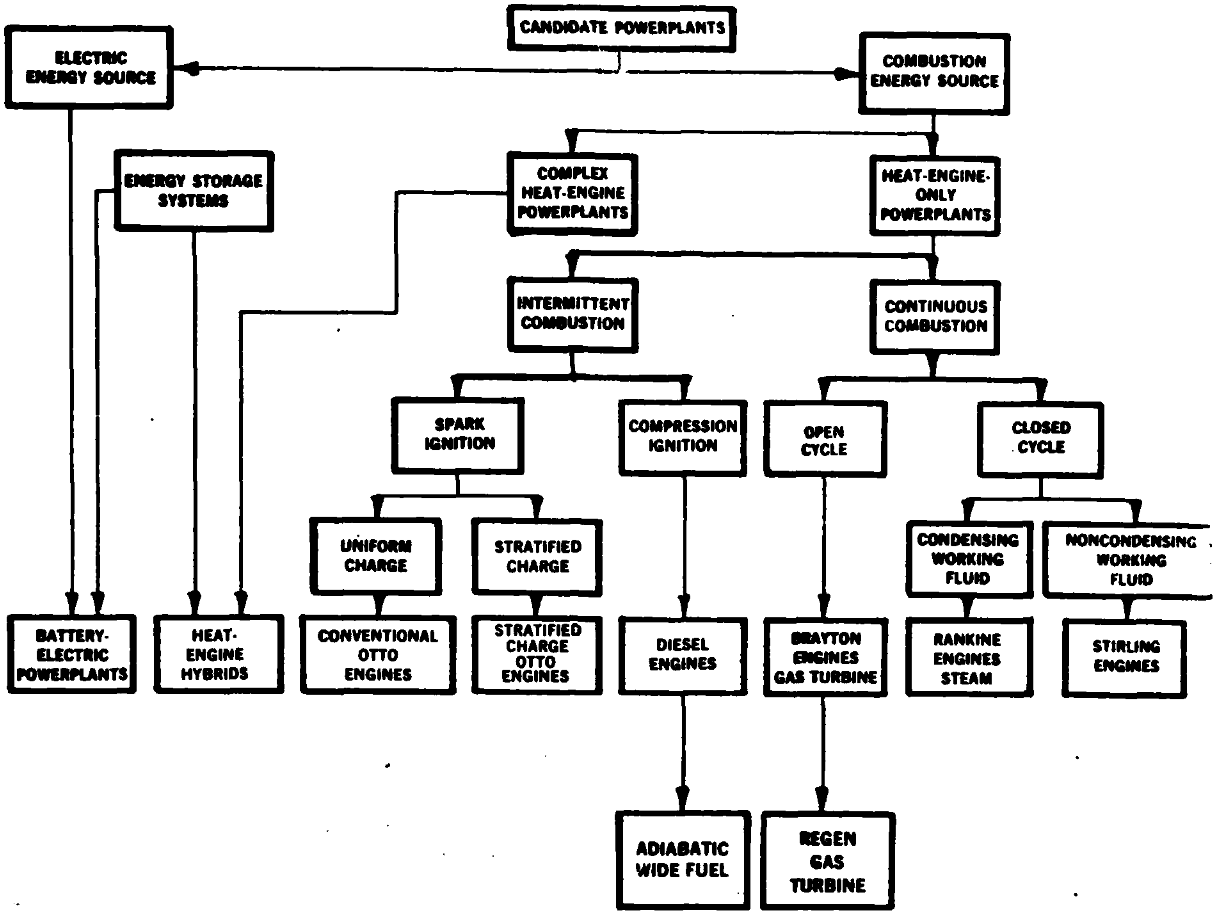

Fig. 1 - Engine Candidates

evolved a two-fold engine R&D strategy. This paper traces the evolution of this strategy with first a discussion of the Army's highest priority ground engine R&D goals. These goals have been quantified by a series of parametric trend charts, an understanding of which leads to an appreciation of the first part of the strategy, the limitation of TACOM's R&D efforts to that range of engines wherein there are no cost effective commercially available engine options. The paper then introduces the second part of the strategy, namely the development of an objective, quantifiable methodology which integrates the highest priority goals into an overall evaluation of the cost/combat (or operational) effectiveness of candidate engines. This approach to engine selection potentially can provide the Army with a simple, quick evaluation leading to the elimination of the less desireable alternatives. The methodology is applicable to the evaluation of both commercially-available and to Army-developed engines. Of importance, though, is the fact that this methodology determines the relative importance of each R&D goal because it is only through the attainment of these goals that a candidate engine can show up well in the evaluation.

This paper shall, therefore, explain first, the critical engine R&D goals and then the two-fold engine Research, Development, and Acquisition strategy which follows.

PROPULSION SYSTEM GOALS

Figure 2 summarizes TACOM's highest priority Propulsion System goals. The Army is interested in developing and procuring combat effective engines which provide good overall mission fuel economy, wide fuel tolerance and, in combat vehicles, high power density and rapid acceleration. Additionally, the engines must be reliable, durable and maintainable with the minimum resources, (money and manpower). All this must be achievable at the best possible overall cost. These goals, of course, are often competing and the final engine design will be determined by the relative weighting assigned to each goal.

TACOM has conducted parametric

PROPULSION SYSTEM GOALS

COST - LOW LIFE CYCLE COST

POWER DENSITY - SMALL COMPACT PROPULSION SYSTEM

PERFORMANCE - HIGH PERFORMANCE, EFFICIENT, WIDE FUEL TOLERANCE

RAM-D - RELIABLE, AVAILABLE, MAINTAINABLE, DURABLE

Fig. 2 – Propulsion System Goals

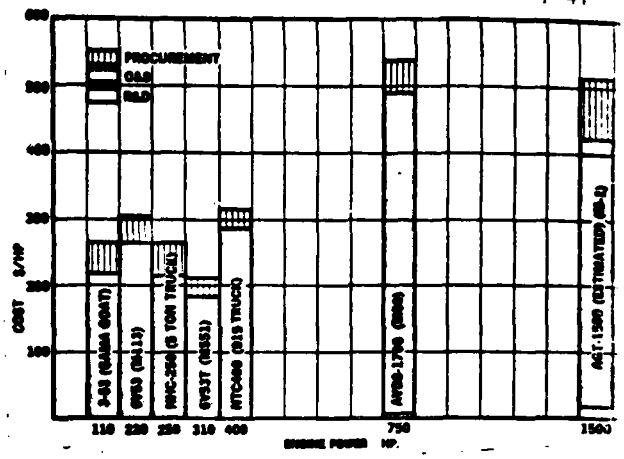

Fig. 3 – Engine 20 Year Life Cycle Cost

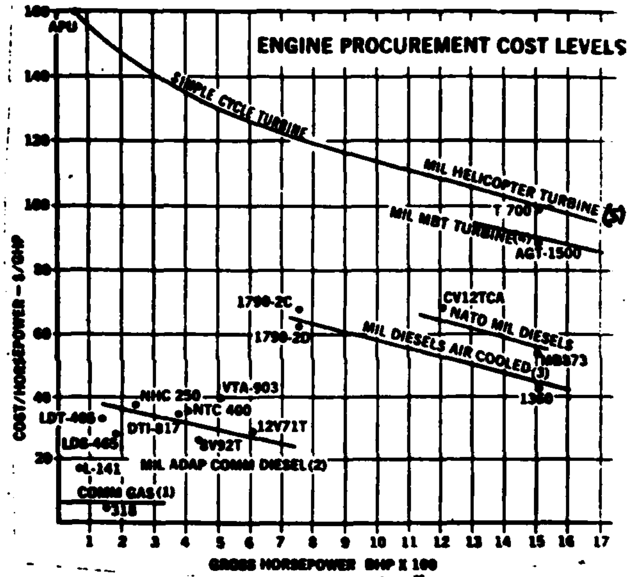

Fig. 4 – Engine Procurement Cost Levels

studies which quantify the values of these goals for various engine classes. The results of these parametric studies of the cost, power density, performance and RAM-D goals are discussed next.

COST

The DOD defines "Life Cycle Cost (LCC)" to be the summation of the costs required to develop and test (R&D cost), procure (acquisition cost), and operate and support (O&S) for the life of the system (including overhaul cost, if any). The life of most weapon systems is 20 years and therefore, the cost of operating and supporting the system for 20 years is usually the largest element of life cycle cost.

The LCC of various engines which the US Army has in operation is shown in Figure 3. The first five engines shown, which cost approximately \$250 per horsepower for 20 years of life, are commercial engines. The last two engines are the Main Battle Tank (special military) engines which have LCC levels of approximately \$500 per horsepower for 20 years of life. These LCC data are not directly comparable between vehicles since the use and mileage of each vehicle class varies. Note that the R&D costs typically are a small element (less than four percent) of the total LCC.

Each cost element of LCC can be analyzed to determine parametric relationships for the various classes of engines; for example, Figure 4 is a chart of engine procurement costs and ~~it display~~ displays some parametric cost trends for five classes of engines and five procurement cost levels, commercial passenger car high production rate gasoline engine (\$7/HP), commercial truck medium production rate diesel engines (\$30/HP), military (tank) diesel engines (\$60/HP), military (tank) regenerative gas turbine engines (\$90/HP), and military helicopter gas turbine engines (\$100/HP). These procurement cost data are not directly comparable between engines since the production rate, time frame, and accessories vary ~~varies~~ for each engine procurement. Nonetheless, these types of parametric cost data can be used to estimate the cost of engine design candidates which have not yet entered production and are often useful in preliminary evaluations.

A significant conclusion drawn from Figures 3 and 4 has prompted the formulation of the first aspect of the TACOM R&D strategy. It is apparent that commercial engines are less expensive than military-designed ones. There are a variety of reasons for this: lower procurement cost, lower R&D cost, but principally lower O&S cost. The lower O&S cost of the commercial engines arises largely from the lower maintenance costs, as fuel costs per horsepower are roughly equal. It follows then, that it is more cost effective for the Army to procure commercial engines whenever possible (with military adaptation, as necessary). Only when there are no suitable commercial options (as occurs in the very large engines), should a purely military engine be considered.

POWER DENSITY

Power density is a measure of the ability to package the engine or power unit in a small volume with minimal weight. This feature is particularly important to combat vehicles wherein excessive volume committed to propulsion greatly exacerbates the vehicle weight problem through the extra armor protection required to house the unit. Vehicle weight, in turn, is a significant consideration because of its adverse effect upon performance (fuel economy and acceleration), cost, and air transportability.

Power density is described quantitatively in terms of specific weight and specific volume, that is, the weight or volume per horsepower. Figure 5 presents the engine specific weight as a function of design power. Each engine class (turbine or diesel) is seen to form a separate curve. The lowest line represents the simple cycle turbines and demonstrates the very low specific weight of that type of engine. Of course, this is the reason that simple cycle turbines are selected in aircraft and helicopter applications. The recuperated and regenerated gas turbine engines have considerably higher specific weights. The weight penalty here is associated with the heat exchanger and the required ducting. There is a distinct break in the ~~tread~~ trend at the low-power end representing the regime of the automotive gas turbine. The reason is two-fold; first, the heat exchanger is, thus far, a rotating regenerator which provides greater effectiveness with a smaller volume and weight (but is limited to lower pressures); and, second, the volumetric and weight constraints are imposed more severly upon automotive applications than on trucks.

Diesel engines, except for the adiabatic diesel, tend to have higher specific weight values than the turbines. The diesels fall into

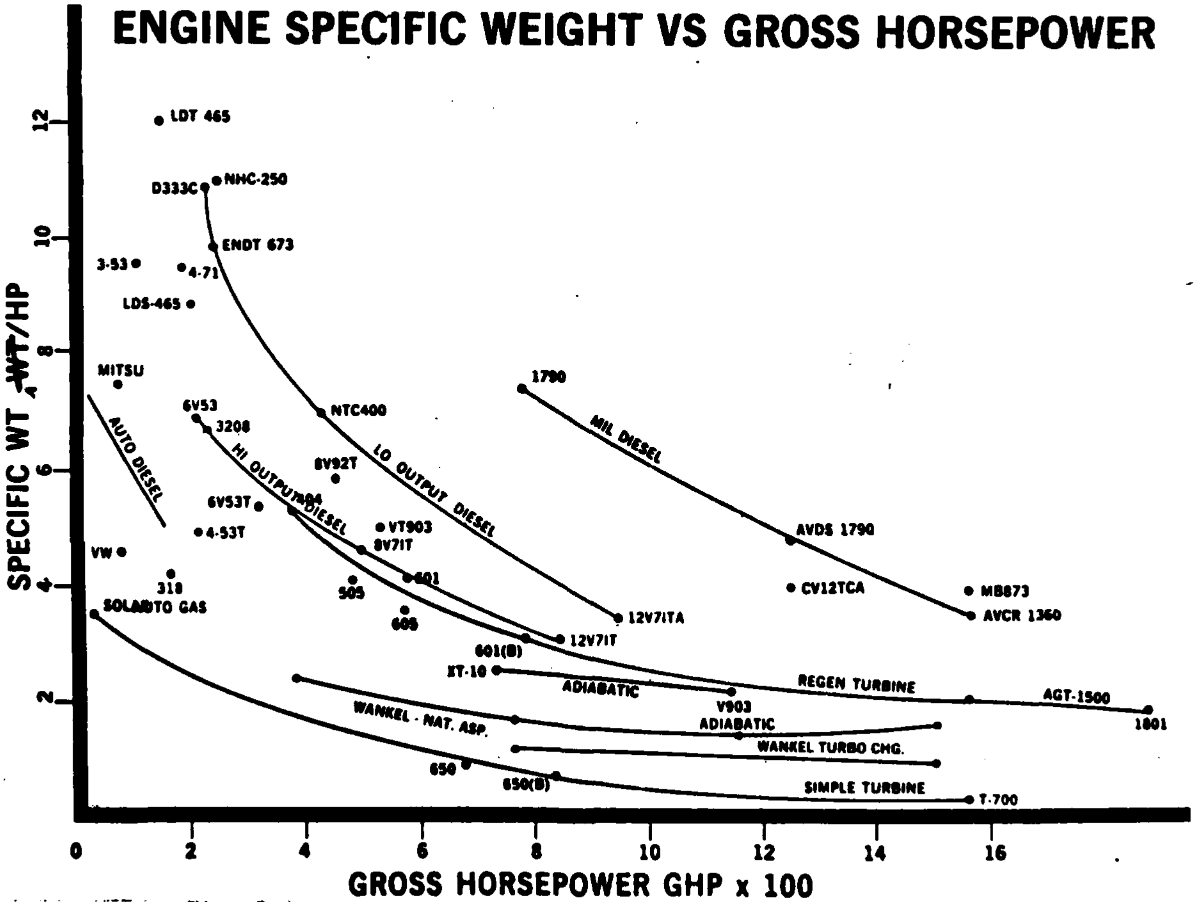

Fig. 5 - Engine Specific Weight

four separate classes. The first includes air cooled diesels of exclusive military design and use. The second is the range of truck, construction equipment, and militarized commercial diesels that span the low-to-high output diesel range. The third is the adiabatic diesel that shows well here because of its highly efficient extraction of input energy at little penalty in weight or volume (the turbocompounding device). The fourth, and last, is the automotive-sized diesel. In the automotive-sized diesels (less than 200 HP), there is a break in the trend represented by the band of conventional low-to-high output diesels. This again represents the special constraints imposed by automotive design on the weight and volume, even at the possible expense of the extraordinary durability attributed to the truck diesel.

Figure 6 presents the specific volume, which is the second measure of power density. The trends and arrangements here are similar to those in Figure 5 and one may draw the same conclusions. Comparisons such as these however, do not provide a complete picture. The propulsion system in a typical fielded combat vehicle occupies approximately 40% of the under-armor hull volume. Of that, only a portion is taken up by the bare engine; the rest is occupied by ancillary equipment such as radiators, air cleaners, induction and exhaust ducting, transmission, and fuel. Fuel is considered here in the volumetric study as there may well exist a trade-off between engine size and efficiency on one hand and mission fuel required on the other. For example, the AGT-1500 gas turbine engine used in the M1 Abrams Tank has a recuperator which imposes a volumetric penalty of about 5 ft^3, but in doing so provides a 40% reduction in the average mission fuel ~~economy.~~ consumption

Figure 7 summarizes the volume breakdown of the propulsion package in a tank. Note that if the engine size alone is reduced by one-half, the total propulsion system volume is reduced by only 17½%. If however, an adiabatic engine were successfully developed for combat vehicles, not only would the engine size be reduced by 50%, the cooling system would be reduced by 66%, and the fuel system by 40%, for a total system propulsion systems volume reduction of 39%. Dramatic

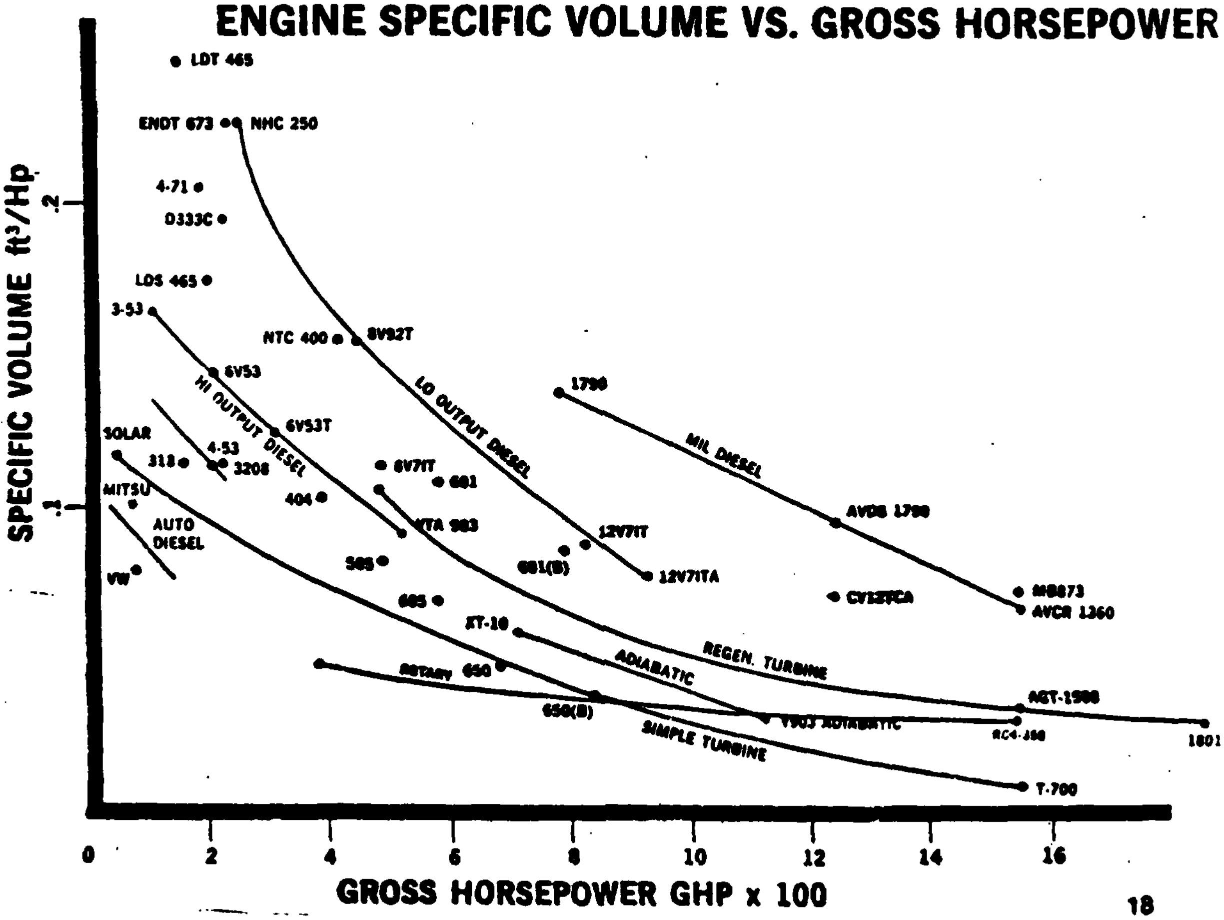

Fig. 6 – Engine Specific Volume

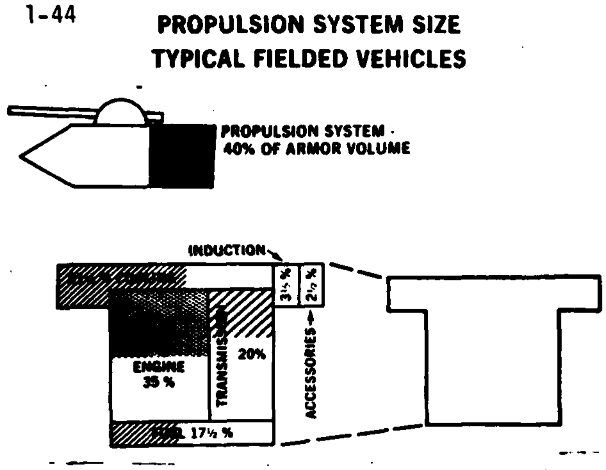

Fig. 7 - Propulsion System Size, Typical Fielded Vehicles

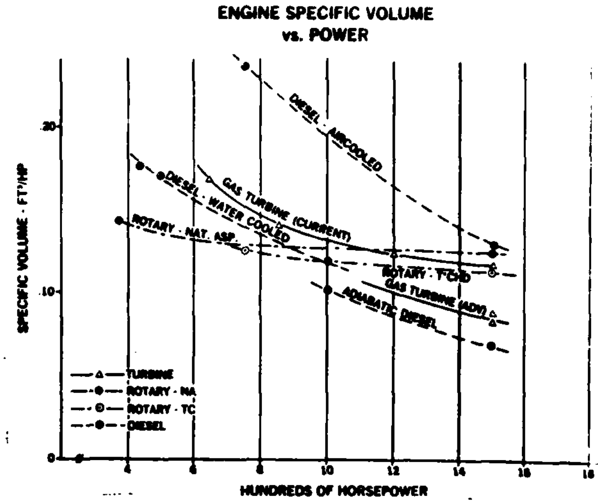

Fig. 8 - Engine System Specific Volume

reductions in the size of advanced rotary and gas turbine powerplant installations also are possible. Nonetheless, the major reduction of some sizeable ancillary equipment and fuel needs in the adiabatic diesel give that engine a major boost toward meeting TACOM's power density goal. By comparison, the gas turbine engine's inherently good power density is somewhat offset by two factors. First, the recuperated gas turbine engine today does not possess a fuel economy (a performance parameter) equal to that of a good diesel, and hence, greater fuel capacity is required for a given range. Second, the gas turbine today provides less work per pound of air, and hence, requires higher air flow, which leads to greater air induction, filtration, and exhaust volumes than are required by the diesel.

One approach to exploring the power density of the propulsion system as a whole is presented in Figure 8. This portrays the specific volumes not of bare engines, but of engine systems. Many of the data points are estimates based upon empirical rules formulated from previous experience. Included in the volume count are engine, engine cooling, if any, induction/exhaust, air filtration, and fuel for a 275 mile cross-country cruise. Auxiliary Power Unit (APU) function, if separate, and transmission volumes are not included. A comparison between Figures 6 and 8 reinforces the validity of treating the specific volume of the entire system, rather than that of the bare engine. First, the present regenerative gas turbine system at high power is seen to be only comparable in volume to that of the military, air-cooled diesels (e.g., AVCR-1360 vs AGT 1500) and largerthan could be expected from liquid-cooled diesels extrapolated to these power levels. Second, the Wankel or rotary engine system at a high power level is no better than the regenerative gas turbine or air-cooled diesel systems. At lower powers (below about 900 HP), the rotary system volume becomes superior even to that of the liquid-cooled diesels, a fact attributable to its flat slope on the curve implying a uniform scaling with size. As a system, the adiabatic diesel looks much better than it did as a bare engine alone because of the absence of a cooling system and the reduced fuel requirement.

Due to the impact of power density on so many features of importance to military vehicles (performance, cost, and transportability), this goal assumes major proportions in the development of fukture engines as well as in the selection of existing engines for near-term systems. For future engines, Figure 8 projects some expectations of what might be attained. To achieve this power density, close integration of the engine/transmission system will be required.

PERFORMANCE

There are three performance parameters that TACOM considers as prime: Vehicle acceleration, fuel economy, and multifuel capability. Acceleration, useful to combat vehicles for survivability, can be viewed in terms of the vehicular horsepower-to-weight ratio. Figure 9 shows this ratio for a variety of vehicles. Note that current tanks, such as the M60 and the Russian T-64, are at 14 horsepower per ton power level. The new combat vehicles, M1 and M2, have larger powerplants which produce approximately 25 horsepower per ton. For reference, passenger car power level is approximately 75 horsepower per ton. The relationship between power-to-weight ratio, acceleration, and survivability is seen in Figure 10. This

ENGINE HORSEPOWER VS VEHICLE GROSS WEIGHT.

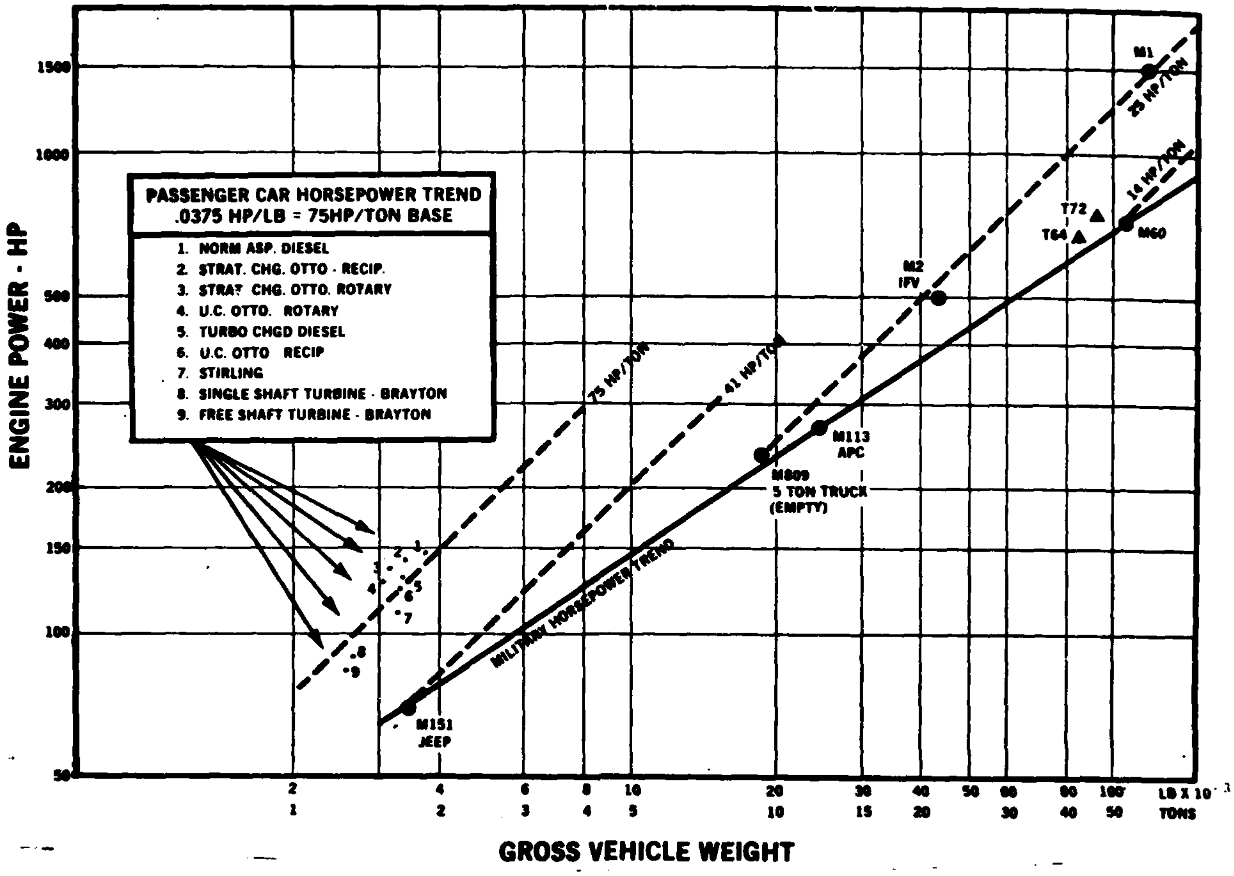

Fig. 9 - Engine Horsepower vs Vehicle Gross Weight

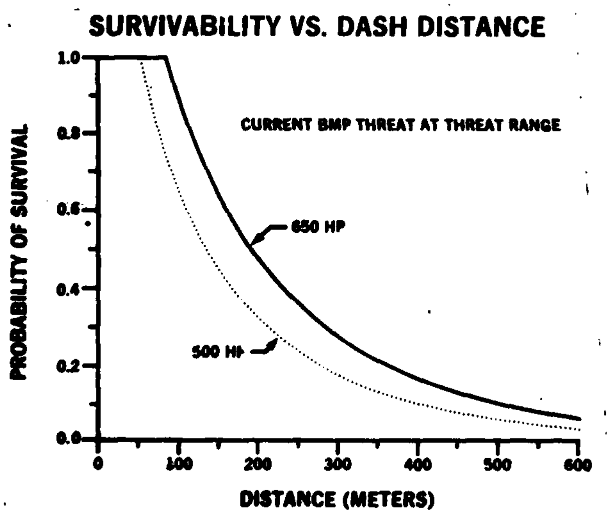

Fig. 10 - Survivability vs Dash Distance

example utilizes the Army's mobility and threat models to compute the probability of survival as a function of exposure distance to a typical weapon for a 22-ton tracked vehicle with, first, a 500 HP engine and, second, an 650 HP engine. The shorter exposure time over a given distance by the more rapidly accelerating, higher powered vehicles allows less reaction, tracking, and reloading time by the threat weapon.

Fuel economy is important to both tactical and combat vehicles because of its impact on LCC and logistics. In addition, for combat vehicles, fuel must be placed largely, or better yet, exclusively under armor protection. Thus, the more fuel needed for a given range requirement, the heavier and more costly the tank.

Fuel economy in an engine is, of course, usually measured by the brake-specific fuel consumption (BSFC). Figure 11 presents the

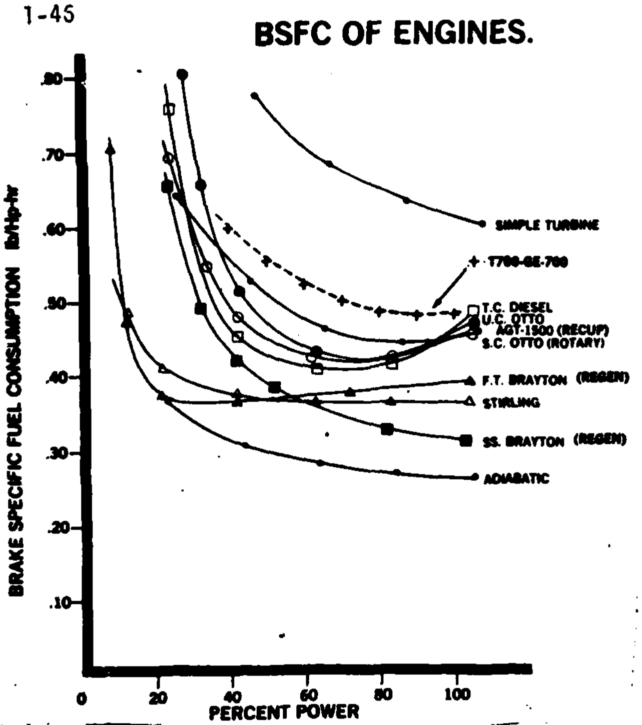

Fig. 11 - BSFC of Engines

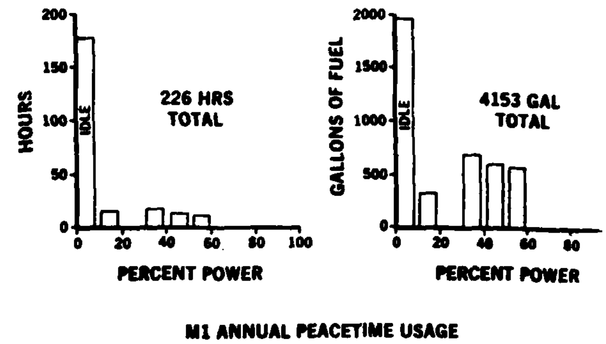

Fig. 12 - M1 Annual Peacetime Usage

typical BSFC curves as a function of percent power for a variety of engine types. These data are from Reference (1) and army sources. Note that the simple cycle gas turbine that stood out so well in Figure 6 because of its excellent power density, now stands out for its very high fuel consumption: Space gained in small engine volume will be taken by fuel. Consequently, this type of engine is not suitable for ground vehicles. In the middle range are a variety of diesels, gasoline reciprocating, rotary, regenerated free-turbine and single-shaft gas turbines. The bottom line shows the demonstrated fuel consumption for the adiabatic diesel engine. This engine is the most fuel efficient ground vehicular engine in the world. It represents a severe challenge to the gas turbine. To be competitive, the gas turbine will have to operate at a high turbine inlet temperature, perhaps 2,500 °F, and be highly recuperated and possibly intercooled. While this will provide high efficiency at high power, there still remains the problem of low efficiency at low and idle power for as Figure 11 shows, there is a dramatic increase in the BSFC of all engines at sufficiently low power. In aircraft and line-haul trucks, this is less a concern as their duty cycles are predominatly at higher power. Figure 12 shows the peacetime annual duty cycle for Army Combat vehicles. Other relevant cycles are the 24 and 48 hour battlefield cycles. Shown also in Figure 12 is the fuel consumed by the AGT-1500/M1 tank at each power point of the cycle. Thus, the idle and low power engine fuel economy is very important in combat vehicle applications.

The improvement in low power fuel economy is achieved by the use of a free power turbine, variable geometry to maintain a high Turbine Inlet Temperature (TIT) at low power, and adequate regeneration. For the 2,500 °F. TIT just suggested, a recuperator or regenerator capable of operation at 2,000 °F. at idle may be needed. This introduces the need for ceramic materials, such as Silicon carbide or Silicon nitride. Considering the possible pressure ratios (15:1) that may be involved to achieve acceptably low airflows, the use of ceramics in a recuperator becomes a major technical challenge. Several other mechanisms, both thermodynamic and mechanical, have also been proposed to improve low power fuel economy for gas turbines, but will not be discussed in this paper.

The third aspect of the research and development performance goal is the achievement of multifuel capability. The national defense depends on a guaranteed energy supply, in particular, a guaranteed supply of liquid hydrocarbon fuels. Alternatives are needed that are domestically controllable; consequently engines must be developed to operate on those alternate fuels. The DOD is committed to a long-range program to achieve an orderly transition to synthetic hydrocarbon fuels in the 1985 to 2010 timeframe. In support of this policy, the Army has initiated an alternative fuels R&D program that is expected to yield commerical engine modification kits, thereby allowing the US Army ground tactical vehicle fleet the flexibility of operating on a wide range of conventional and synethic fuels.

The ideal multifuel engine is defined for Army purposes as: "An engine with the ability to operate on a wide range of alternate hydrocarbon fuels (from gasoline to diesel, including shale oil or coal derived fuels, with a wide spread of octane and cetane tolerance) in military vehicles without requiring physic adjustment in the field or compromising engine performance or life." An emergency fuel, as opposed to the alternate fuels described previously, is one with which an engine can be made to operate well enough for the basic purpose to which it was designed, but with which the engine can be expected to suffer some degradation in performance and life.

Figure 13 displays the distribution of fuels of interest according to cetane number and viscosity which largely govern the fuel performance in internal combustion engines. There are other fuels properties, such as lubricity, which also must be considered. Viscosity, but not the cetane number, affects the combustion of gas turbine engines. The important points to understand here are, first of all, that the DOD multifuel definition encompasses a very large range of conditions, and second, that 100% alcohols are not within that range, although alcohol blends may be.

Figure 14 summarizes the multifuel potential of various engine types. Two types of engines have inherently poor multifuel capabiities: Gasoline spark ignition engines because of their octane sensitivity and diesel open-chamber compression ignition engines because of their relative cetane sensitivity. For those reasons, conventional open-chambered engines will be phased out of the Army inventory and replaced by wide fuel tolerant engines in the 1985-2000 timeframe. Gas turbines and Stirling engines are potentially good multifuel engines because they are continuous combustion engines.

The three performance considerations discussed here do not exhaust those of interest to the Army. Two others are worth highlighting. The first is cold-start capability. The Army requirement is for start-up within one minute using only the vehicle batteries with DF-2 fuel at an ambient 20° F., and DF-1 at an ambient -25° F.

The second is the torque characteristic and output RPM of the engine. The significance here, for existing systems, is the availability of a suitable off-the-shelf transmission. For new systems, the significance is the ability to tailor the transmission for minimum size. In this latter situation, the benefit accrued is measured in terms of the power density, if that term is defined to include the transmission (as it was not in Figure 8). Figure 15 shows torque vs output speed examples of three engines, a diesel, a rotary, and a free power turbine gas turbine. The gas turbine, in this case, could impact both size and efficiency of the transmission by elimination of the torque converter that is required for the other engines shown. Furthermore, the typically high output speed of the power turbine might

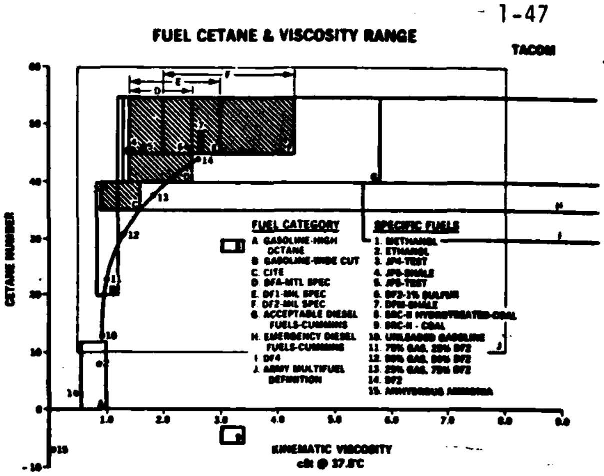

Fig. 13 - Fuel Cetane and Viscosity Range

ENGINES VS. ALTERNATIVE FUEL SUITABILITY

Fuel	Spark ignition	Compression ignition	Stratified charge	Stirling. Gas turbine
Gasoline	OOO	O	OOO	OOO
Gas oil		OOO	OOO	OOO
Wide cut		O	OOO	OOO
LPG	OO	O	OO	OO
Alcohol	OO	O	OO	OOO
Hydrogen	O		O	O

OOO Very suited　　O Technically just possible
OO Not ideal

Fig 14 - Alternate Fuel Suitability of Engines

ENGINE TORQUE CHARACTERISTICS

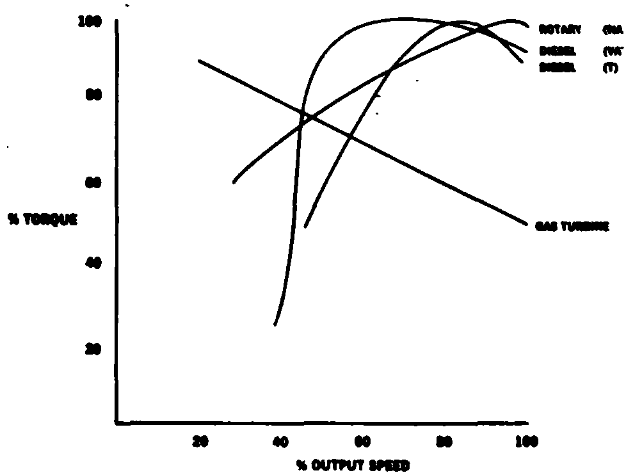

Fig. 15 - Engine Torque Characteristics

also be used to advantage by providing the gear changing at high speed and thus, low torque. This also could materially reduce the transmission size, although with, perhaps, a minor compromise in efficiency. Torque and total power together do not completely address the acceleration requirement, of course. Engine response time to power demand must also be addressed and, indeed, can be of considerable impact on gas turbine and highly turbocharged diesel performance.

In summary, then, the principal performance requirements for the Army are acceleration for combat vehicles, fuel economy, and multifuel capability. These characteristics impact survivability, LCC, and availability. Ancillary considerations of cold start and torque impact availability and power density, both of which affect the combat effectiveness.

RAM-D

RAM-D is the acronym for reliability, availability, maintainability, and durability. The impact of these collective considerations has a heavy influence on the utility of an engine to the Army. Excessive maintenance, either scheduled or unscheduled, impacts the number of vehicles available for duty at any given time. Additionally, reliability impacts the conduct of a battle by further reducing the number of vehicles succeeding in the execution of the required missions. RAM-D also impacts the LCC significantly as one of the major components (with fuel) of the operations and support costs. Thus, improvements in this area have a marked impact on both sides of the cost-effectiveness equation.

Figure 16 shows the historical Army data for the mean time between critical failures (MTBCF) for typical engines. Note that the best commercial and military diesels achieve 600 hours between critical failures. The RAM-D experience of gas turbines in the aircraft field has been remarkable. Nonetheless, the ground vehicular application is somewhat different and the RAM-D cannot be expected to be entirely similar. The Army's experience with the AGT-1500 gas turbine engine in the M1 tank has been too short, as yet, to provide mature RAM-D data that do not reflect the learning trials of both the user and the manufacturer.

The Army goal for future combat engines is 1,000-hours MTBCF and 2,000-hours life. Achievement of this goal will have a marked impact on the LCC and on the combat or operational effectiveness of the vehicle through improved availability and reliability in the field.

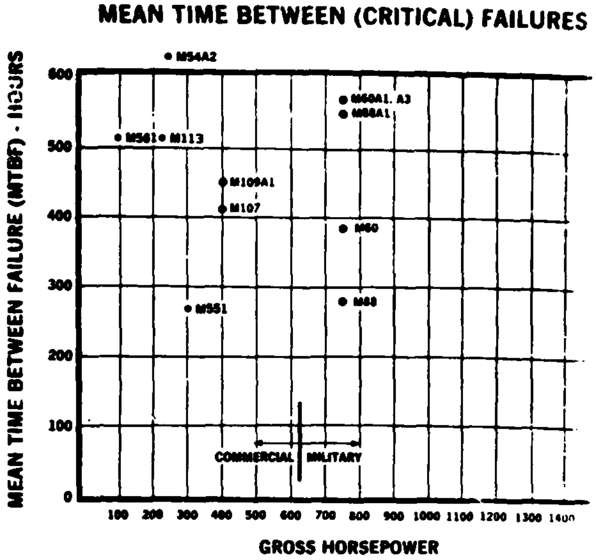

Fig. 16 - Mean Time Between Critical Failures

TACOM RESEARCH, DEVELOPMENT, AND ACQUISITION (R,D&A) STRATEGY

As a consequence of the previously discussed goals and parametric trend studies, a strategy has evolved for the management of engine R,D&A efforts, which involves two parts. The first is the concentration of R&D efforts to that range of engines wherein no satisfactory commercially available engine exists. The second is the development of an objective, quantifiable methodology which integrates the highest priority goals into an overall evaluation of the cost/combat (or operational) effectiveness of candidate engines.

RANGES OF ENGINES

Motivated by its limited resources and a requirement to provide engines for a large variety of tactical and combat vehicle types, TACOM has developed a management strategy to concentrate the limited DOD resources to the highest priorities. There are three size regimes: Below 500 HP, 500 to 1,000 HP, and over 1,000 HP. Each of these regimes is characterized by a particular relationship to the availability of commercial alternatives which can be exploited.

Below 500 HP, because of the lower procurement cost, ready availability and proven cost effectiveness of commercial engines, the Army will use commercial-base engines. In some cases, however, the Army must develop modification kits to meet special DOD goals, such as wide fuel/synthetic fuel capability while maintaining high efficiency. By combining stratified-charge and adiabatic technology into commercial engines, it appears that these goals can be achieved. Because of the desire to exploit commercial engines, the engine options are generally limited to diesels in this power range. In the 500 to 1,000 HP range, the Army can use either a highly modified commercial engine or a military-designed engine, depending upon the availability of a suitable commercial engine to modify. Modifications may be extensive or minor, but in the case of a diesel engine, higher power is often achieved through increased turbocharging and, in future cases, converting the engine to some degree of adiabaticity.

Increasing the level of turbocharging may require, in addition to reduction of the compression ratio, redesign of the load-carrying parts such as the pistons, rods and bearings to accommodate the higher load. Again, in this size range, only a few commercially designed gas turbine truck engines are currently available. Gas turbine engine higher power can be achieved, within structural and aerodynamic limits, by increasing the compressor/turbine speeds and the TIT. Beyond that, resizing of the air path is necessary, and finally, increased cooling or different materials to accommodate a much increased TIT. These are major revisions to the engine.

In the over-1,000 HP range, commercial engines for vehicle application are nonexistant and the Army must develop unique military engines. The appplication here is tracked combat vehicles, and in particular, the Main Battle Tank. In the past, gasoline reciprocating engines have been used, to be replaced later by diesels. Most recently, a recuperated gas turbine, the AGT-1500, has been employed. For the next generation Main Battle Tank, gas turbine, adiabatic, and rotary engines are all strong candidates. Figure 17 summarizes the above discussion and graphically displays the three power ranges inherently in the first aspect of TACOM's R,D&A engine strategy.

Consistent with this "power range" strategy, Figure 18 shows how gas turbine engines may be applied to a range of military vehicles. Commercial gas turbines such as the GT-601 and GT-404 turbines could be adapted for military application with slight modification, in the 300 to 600 HP range which would have application to the vehicles shown on the right. These commmerical gas turbines could be up-rated to 700-1,000 HP and applied to a range of military vehicles shown on the right. In the 1,500-2,000 HP range, an entirely new gas turbine would have to be developed for the future Main Battle Tank.

Figure 19 shows how adiabatic diesel engines may be applied to a range of military vehicles. Starting with a commercial 250 HP

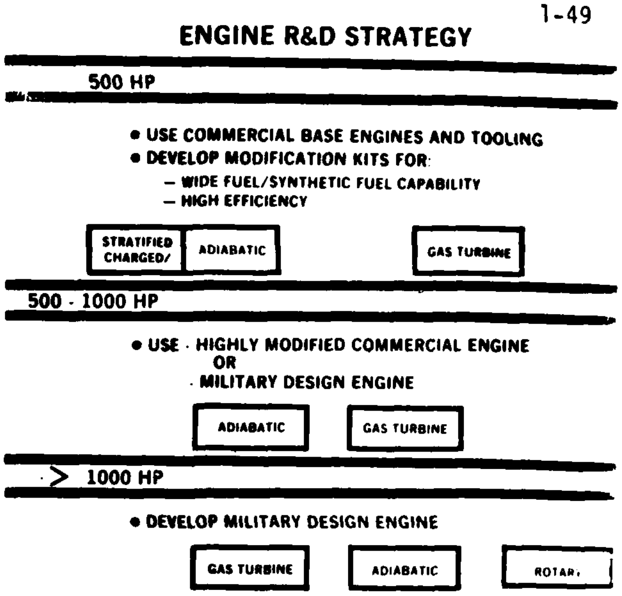

Fig. 17 - Engine R&D Strategy

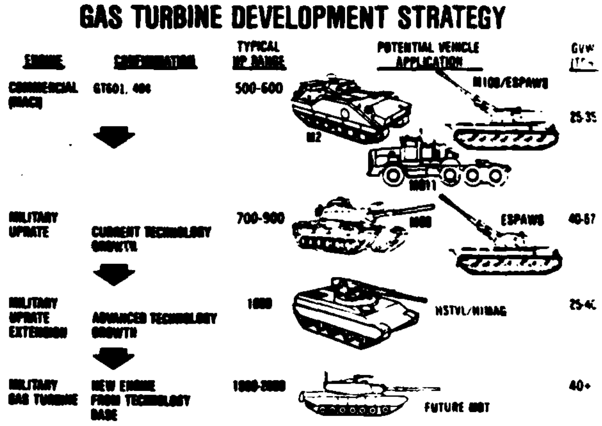

Fig. 18 - Gas Turbine Development Strategy

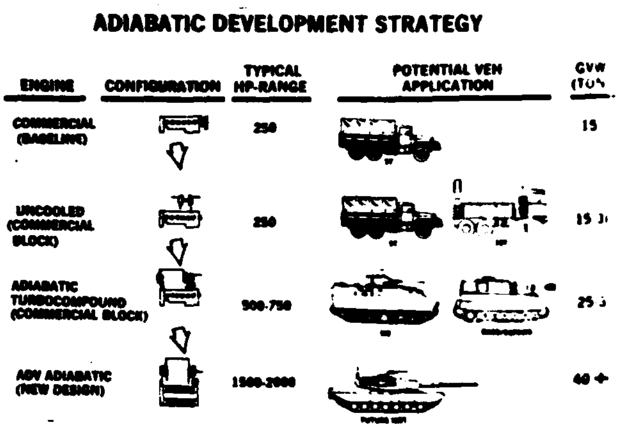

Fig. 19 - Adiabatic Development Strategy

engine, which is in the 5-ton truck, an uncooled, turbocharged version of this engine incorporating some ceramics could be applied to 5- and 10-ton trucks. By adding a turbocompound system and more insulation, it is technically feasible to build a 500-700 adiabatic engine, again based on a commercial engine block. In the Main Battle Tank category, the adiabatic diesel engine must begin with an all new design to be competitive with the good power density of gas turbine and rotary engines.

COST/OPERATIONAL EFFECTIVENESS METHODOLOGY

The second part of TACOM's engine R,D&A is the employment of a standardized cost/operational effectiveness methodology which integrates the previously discussed goals into an objective quantification of the relative vehicle benefits afforded by each engine candidate.

For a combat vehicle, operational effectiveness becomes combat effectiveness and one propulsion engine candidate is judged to be more effective than another if it can be shown that its performance and dependability are such that its selection results in a higher number of combat vehicles successfully completing the prescribed mission. Thus, the approach to evaluating the cost/combat effectiveness of two or more engine candidates is to fix the total budget allocated to the vehicle fleet (for each engine candidate) and then compare the mission success of the candidates. This is done by first determining the number of vehicles, with each type of engine, that can be purchased, operated and maintained for a fixed total dollar investment (this descends directly from LCC analysis), then calculating and comparing the number of combat vehicles that will survive with these engines, giving consideration to the propulsion system performance, availability, and reliability. This concept of effectiveness and a methodology for computation are described in details in Reference (2). The essence of the procedure is discussed below.

Presented in Figure 20 is a flow chart summarizing the principal steps involved in computing and comparing the cost/combat effectiveness of combat vehicle engines. The

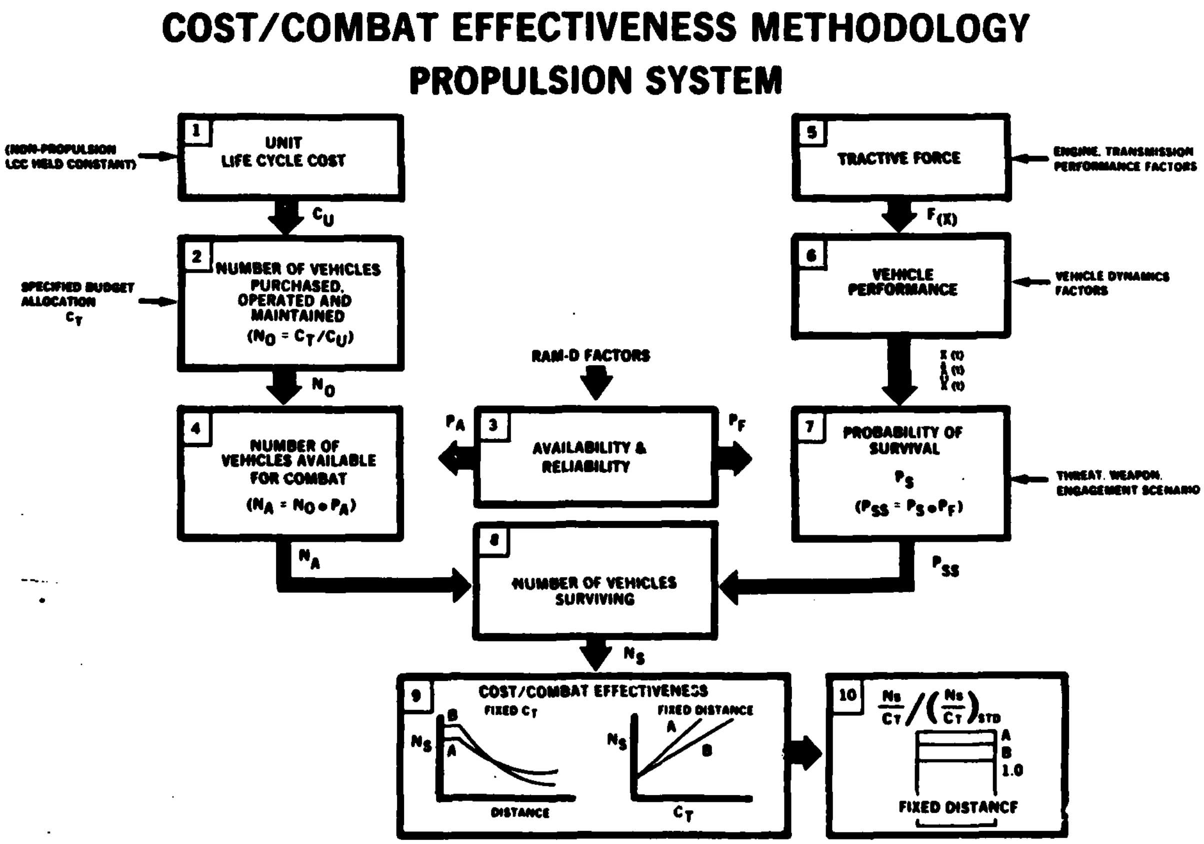

Fig. 20 - Cost/Combat Effectiveness Methodology

branch on the left computes the number of vehicles available for combat, N_A, with each type of engine for a fixed budget allocation, C_T, and the branch on the right computes the probability of successfully completing the mission, P_{SS}, for the combat vehicle employing each candidate engine. These two parameters, number of engines available, N_A, and probability of success, P_{SS}, are multiplied in Block 8 to yield the number of vehicles (with each type of engine) successfully completing the combat mission, N_s. The last step (Block 9 or 10) shows how the results can be presented comparing two different engine candidates, A&B. This comparision is the "bottom Line" result being sought for decision-making purposes. Because of this importance, it is useful to discuss these results in detail.

The graph on the left in Block 9 presents the number of vehicles successfully completing the combat missions as a function of the vehicle exposure distance (i.e., distance between protected defilade positions), a key engagement parameter. For illustrative purpose, the graph shows that the cost/combat effectiveness of the two engine candidate crosses over as distance increases. This happens because the probability of survival is 1.0 for small distances and therefore, the number of surviving vehicles is controlled by N_A, the number of available vehicles. N_A in turn, is affected by engine availability and unit life cycle engine (vehicle) cost, as shown in the Blocks 1, 2, and 4.

At longer exposure distances, the probability of successfully completing the combat mission, P_{SS}, dominates over the effects of the number of vehicles available for combat, N_A. The probability of successfully completing the mission is affected by the acceleration and resulting velocity for each of the two candidate systems. The effect of other engagement parameters, such as threat weapon, range or defensive tactics, also affect the probability of survival of each system.

The graph on the right in Block 9 shows the effect of budget allocation on cost/combat effectiveness offered by each engine candidate. In this graph the distance traveled is fixed and the number of vehicles (with each engine) successfully completing the combat missions, N_S is computed as a function of the budget allocation, C_T.

An alternate method of presenting the results is to calculate the ratio of N_S/C_T (for a fixed distance) for engine candidates A and B divided by the value of N_S/C_T for the baseline vehicle with a baseline engine. It has the advantage of indicating the relative improvement in cost/combat effectiveness of each candidate in comparison to the base vehicle and engine. Such a result is shown in block 10. A similar methodology for tactical vehicles exists but is not discussed in this paper. The above methodology, when employed to evaluate engines for vehicle applications provides guidance for the R&D efforts by identifying the factors which best promote overall vehicle cost/combat effectiveness. In turn, the results of these evaluations provides management with the documentation needed to justify the allocation of R&D resources to those areas indicating the highest return on R&D investment.

CONCLUSION

The US Army Tank-Automotive Command (TACOM) has developed an engine research, development, and acquisition strategy that is intended to better focus the limited DOD resoures and to complement the research and development of other organizations. This strategy is two-fold: First while continuing to monitor and utilize, as appropriate, other engine research, TACOM is concentrating its limited R&D resources on high power (> 500 HP) regenerative gas turbine and adiabatic diesel engines using a commercial base, if possible. TACOM will continue to exploit commercial engines with slight military modifications, as necessary, for low power (< 500 HP) ground vehicle applications.

The second part of the strategy is a propulsion system methodology which has been developed to evaluate the enhancement of vehicle cost/combat effectiveness afforded by candidate engines. The methodology provides for the identification of some of the major goals for the research and development program. This methodology will be further developed and used as an evaluation screening tool to determine objectively the most promising engine alternatives warranting further development, test and evaluation.

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1. M. Dowdy and A. Burke, "Automotive Technology Projections, SAE paper 790021, February, 1979.

2. P. Glance and H. Cohen, "Evaluation of Engine Designs SAE paper ~~to be~~ presented at the 1982 SAE International Congress and Exposition, February 22-26, 1982.

COMBUSTION FUNDAMENTALS RESEARCH FOR GAS TURBINE ENGINE

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The combustion research and technology programs that are conducted and managed by the NASA LeRC Combustion Branch cover a wide spectrum of activities, from fundamental studies of combustion phenomena to applied research efforts on gas turbine combustors. The focus of these programs is to provide the fundamental information, analytical models, and generic information to designers of future gas turbine engines.

The combustion research portion of the AVRADCOM Propulsion Laboratory research program is completely integrated into the NASA research program, providing both personnel and resources.

Over the last few years increased emphasis has been placed on fundamental and generic research at LeRC with less systems development efforts. This is especially true in combustion research where the area of combustion fundamentals has grown significantly in order to better address the perceived long term technical needs of the aerospace industry. The main thrusts for this combustion fundamentals program are as follows:

Analytical Models of Combustion Processes
Analytically characterize the governing physical phenomena which occur during combustion and in the fluid dynamic processes associated with gas turbine combustors.

Model Verification Experiments
Provide benchmark quality data to assess the accuracy of analytical models and to identify model deficiencies.

Fundamental Combustion Experiments
Achieve a more complete and basic understanding of the fundamental aerodynamic and chemical processes occurring in chemically reacting flows.

Advanced Numeric Techniques
Improve computer codes in terms of efficiency, numerical accuracy, and display of results.

In each of these areas there are several research projects, including grant activities, contracts, and in-house projects. A review of these projects was recently held at LeRC, and a conference publication with project summaries will be published. This presentation will give an overview of the program with several projects highlighted as examples of the program.

National Aeronautics and Space Administration

DEPARTMENT OF THE ARMY
PROPULSION LABORATORY

COMBUSTION RESEARCH

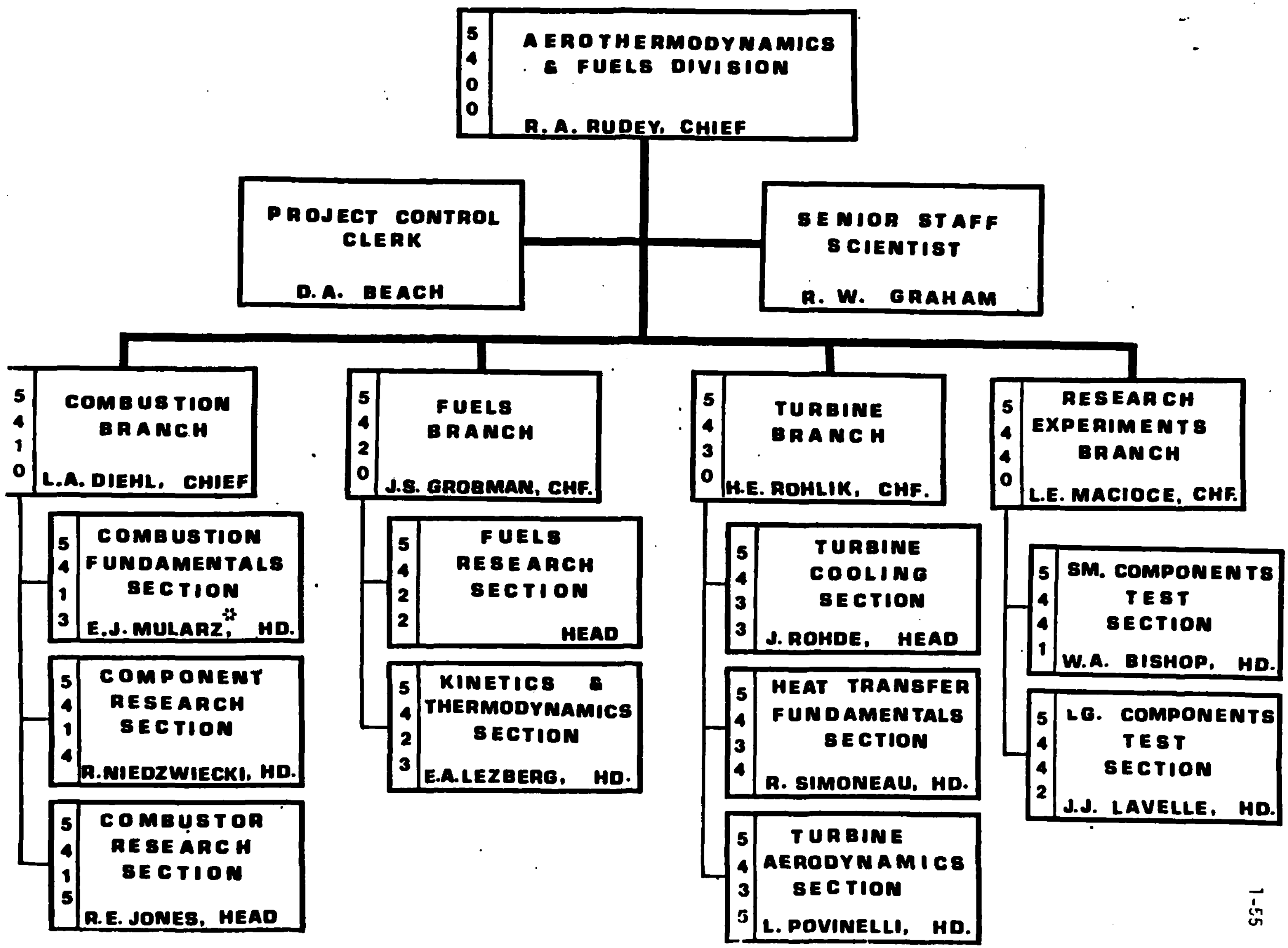
COMBUSTION FUNDAMENTALS RESEARCH FOR GAS TURBINE ENGINES

BY E. J. MULARZ

PRESENTED AT

ARO/MERADCOM ENGINES/FUELS WORKSHOP

DECEMBER 7-8, 1982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- CONDUCT OF MODEL VERIFICATION EXPERIMENTS
- CONDUCT OF FUNDAMENTAL COMBUSTION EXPERIMENTS
- DEVELOPMENT AND APPLICATION OF ADVANCED NUMERIC TECHNIQUES
- MANAGMENT AND CONDUCT OF HOST SPONSORED ANALYSIS/EXPERIMENTS

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  - FUEL EFFECTS
  - FLAME RAD. AND HEAT FLUX
- COMBUSTOR MODEL VALIDATION EXPERIMENTS
- COMBUSTOR COMPONENT RESEARCH
  - FUEL INJECTORS
  - PRIMARY ZONES
  - LINERS
- DESIGN AND EVALUATION OF FULL SCALE SMALL COMBUSTOR CONCEPTS
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  - CH_4 RAMBURNER TECH.
- COMBUSTOR MODEL VALIDATION EXPERIMENTS
- COMBUSTOR COMPONENT RESEARCH
- DESIGN AND EVALUATION OF FULL SCALE ADVANCED COMBUSTOR CONCEPTS
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*USARTL

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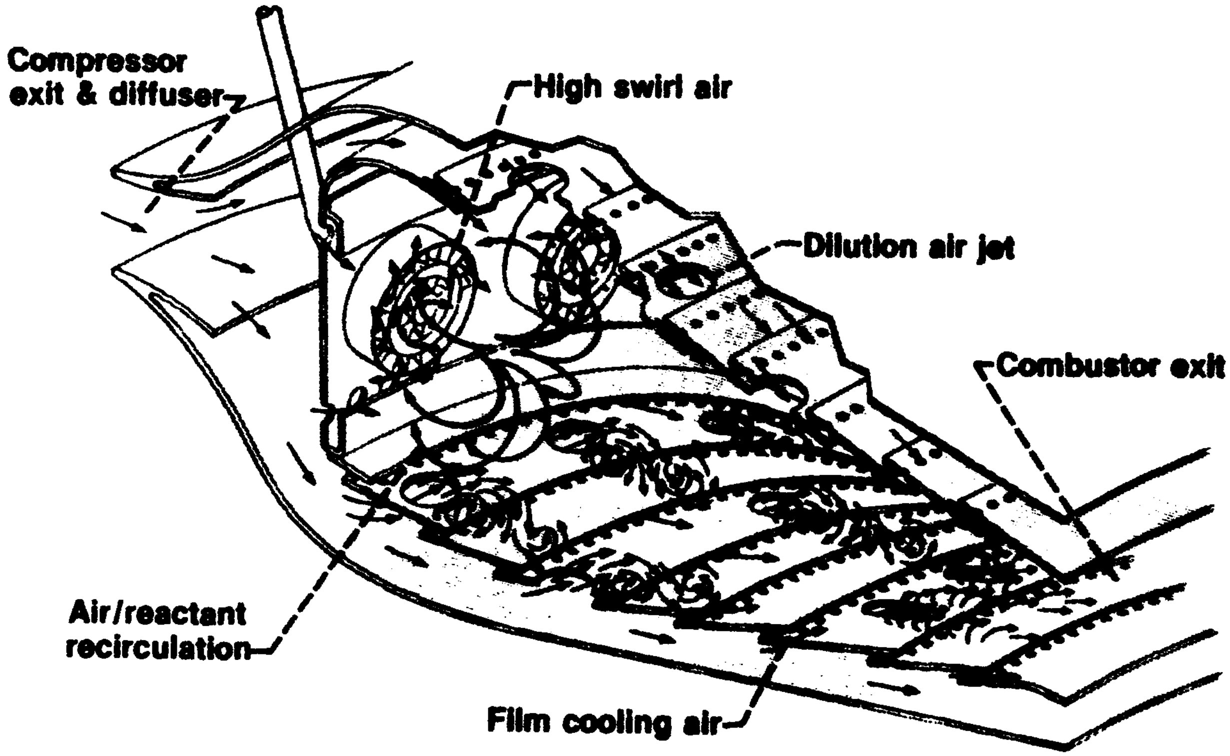
COMBUSTOR FLOW PHENOMENA



- FULLY 3-DIMENSIONAL FLOW
- HIGH TURBULENCE LEVELS
- CHEMICAL REACTION/HEAT RELEASE
- 2 PHASE WITH VAPORIZATION

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THRUSTS

- ANALYTICAL MODELS OF COMBUSTION PROCESSES
- MODEL VERIFICATION EXPERIMENTS
- FUNDAMENTAL COMBUSTION EXPERIMENTS
- ADVANCED NUMERIC TECHNIQUES

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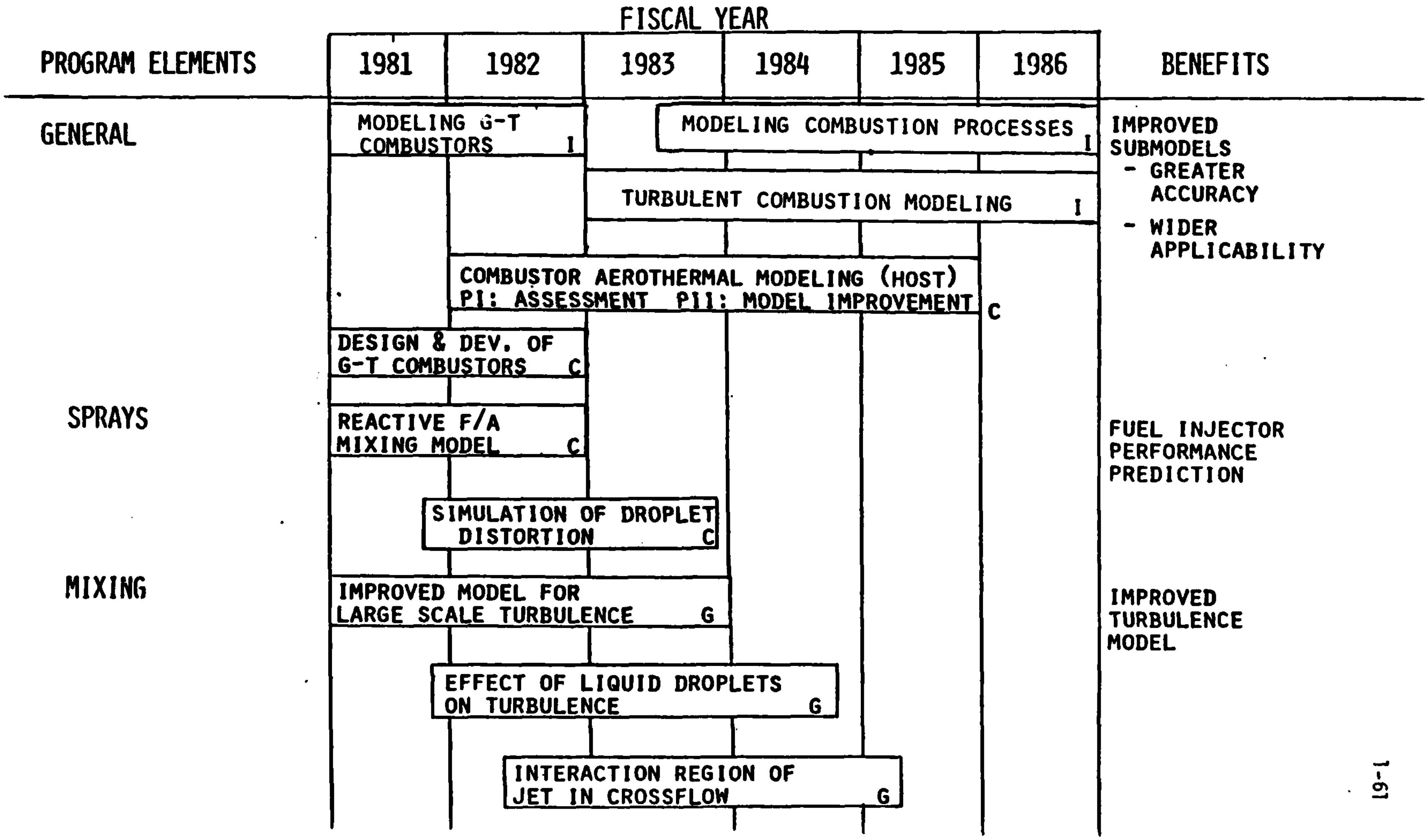
COMBUSTION FUNDAMENTALS

- **ANALYTICAL MODELS**
  - GENERAL
    - TURBULENT COMB. MODELING
    - MOD. COMBUSTION PROCESSES
    - COMBUSTOR AEROTHERMAL MODELING
    - DESIGN & DEV. OF G-T COMBUSTORS
  - SPRAYS
    - REACTIVE F/A MIXING MODEL
    - SIMULATION OF DROPLET DISTORTION
  - MIXING
    - IMPROVED MODEL-LARGE SCALE TURBULENCE
    - EFFECT OF DROPLETS ON TURBULENCE
    - INTERACTION REGION OF JET IN CROSSFLOW
  - RADIATION, CHEMISTRY
    - SOOT, EMISSIONS PREDICTIONS
    - COUPLED TURBULENCE CHEMISTRY MODEL
    - PDF MODELING OF FLAME STRUCTURE
    - SIMUL. CHEM-REACT. MIXING LAYERS
  - COMBUSTION DYNAMICS
    - UNSTEADY FLOW EFFECTS IN COMBUSTION SYSTEMS
    - ANALYSIS OF TURBULENT COMBUSTION CHARACTERISTICS
- **MODEL VERIFICATION EXPERIMENTS**
  - LINER CYCLIC LIFE DETERM.
  - FUEL SPRAY DIAGNOSTIC FACILITY
  - LASER INTERFEROMETRY
  - FUEL INJECTOR SIMILARITY PARAMETERS
  - PRED. SPRAY-COMB. INTERACTION
  - TURBULENCE OF COMB. FLOWFIELDS
  - VELOCITY VISUALIZATION IN GASEOUS FLOWS
  - DILUTION JET MIXING STUDIES
  - MASS & MOMENTUM TRANSFER
  - SPECTRAL RADIANCE & SOOT MEASUREMENTS
  - FLAME RADIATION STUDIES
  - AUTOIGNITION PHENOMENA
  - LASER SAT. FLUORESCENCE
- **FUNDAMENTAL COMBUSTION EXPERIMENTS**
  - BASIC COMBUSTION LAB.
  - FUND. COMB/MIXING EXPERIMENTS
  - FLAME RESEARCH FACILITY
  - DEGREE OF VAPORIZATION EFFECTS
  - SPRAY DROP SIZE EFFECTS
  - LEAN STABILITY PHENOMENA
  - TRANSIENT FLOW COMBUSTOR RESPONSE
  - MECHANISM OF FLASHBACK
- **ADVANCED NUMERICS**
  - ADVANCED GRAPHICS
  - ERROR REDUCTION
  - GRID PATCHING TECHNIQUES
  - FAST COMPUTATIONAL KINETICS

ANALYTICAL MODELS (1 OF 2)



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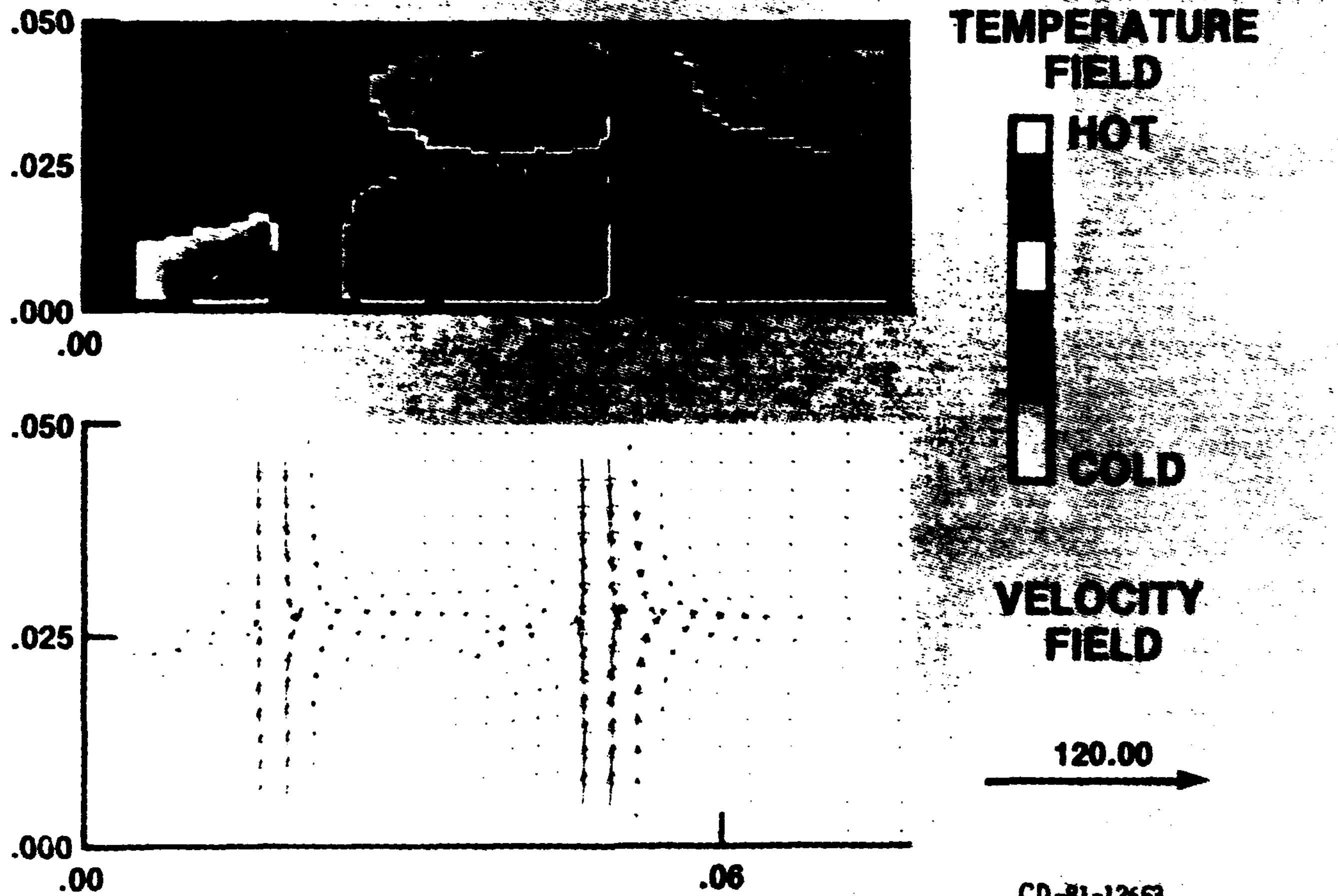
NUMERICAL ANALYSIS OF COMBUSTOR FLOW FIELD



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ANALYTICAL MODELS (2 OF 2)

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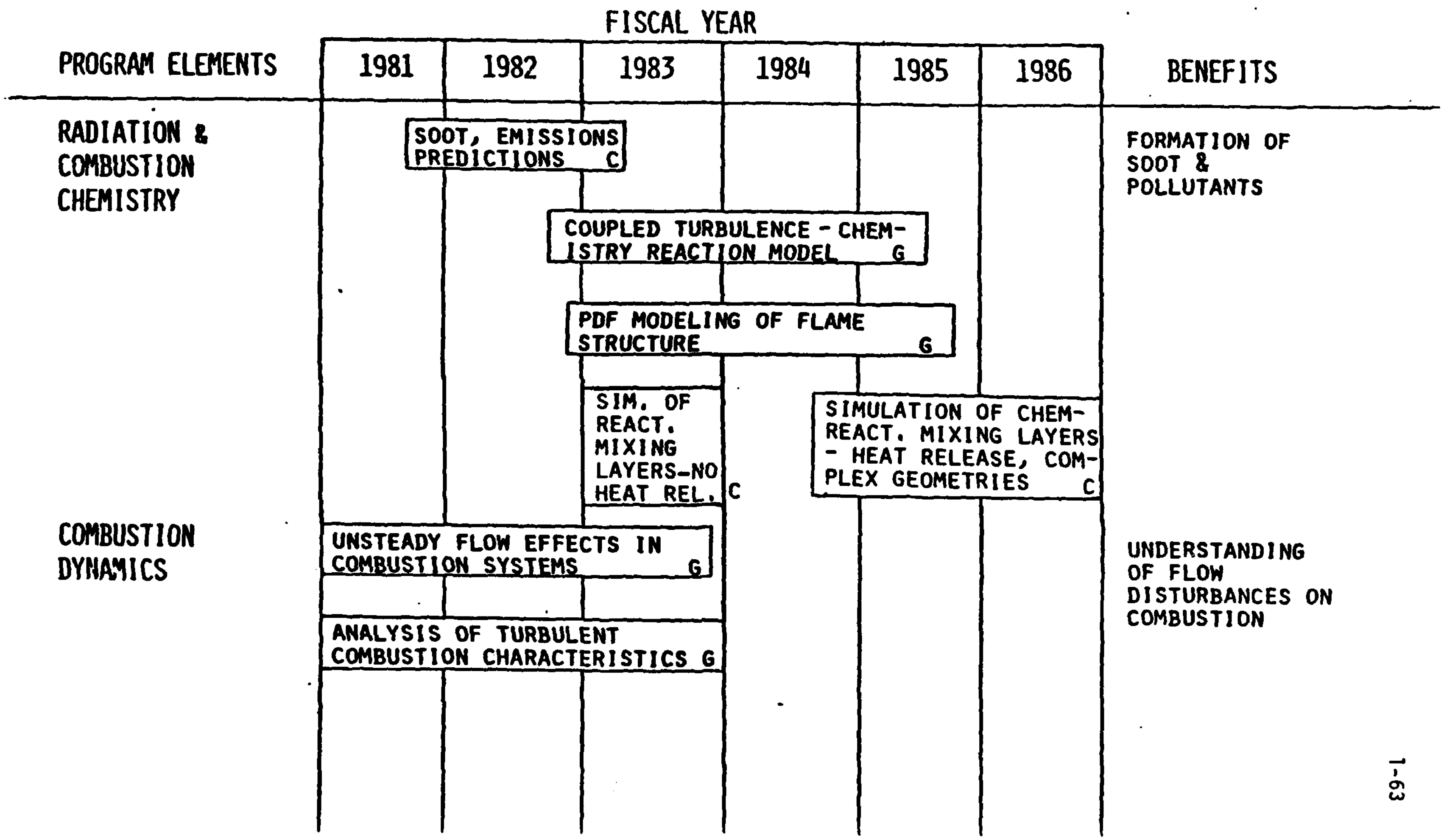

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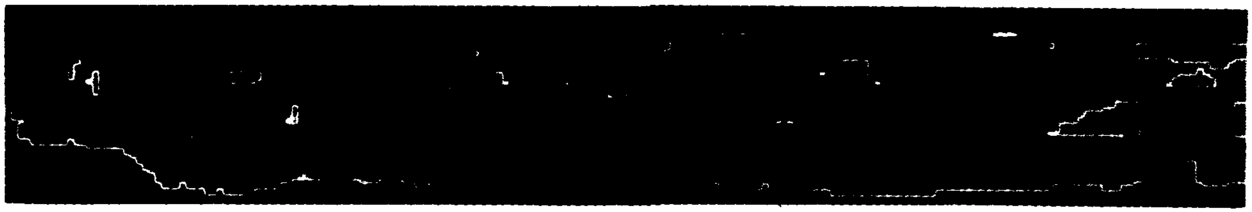
NUMERICAL MODELING
FLOW FIELD WITH COMBUSTION



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MODEL VERIFICATION EXPERIMENTS (1 OF 2)

NASA

PROGRAM ELEMENTS	FISCAL YEAR 1981	1982	1983	1984	1985	1986	BENEFITS
GENERAL	LINER CYCLIC LIFE DETERMINATION (HOST) I						IMPROVED DURABILITY PREDICTION
SPRAYS	FUEL SPRAY DIAGNOSTIC FACILITY PI: NON-REACTING FLOW PII: REACTING FLOW I						FUEL INJECTOR PERFORMANCE PREDICTION
			IMPROVED LASER INTERFEROMETRY C				
	FUEL INJECTOR SIMILARITY PARAMETERS G						
		PRED. SPRAY-COMB. INTERACTION G					

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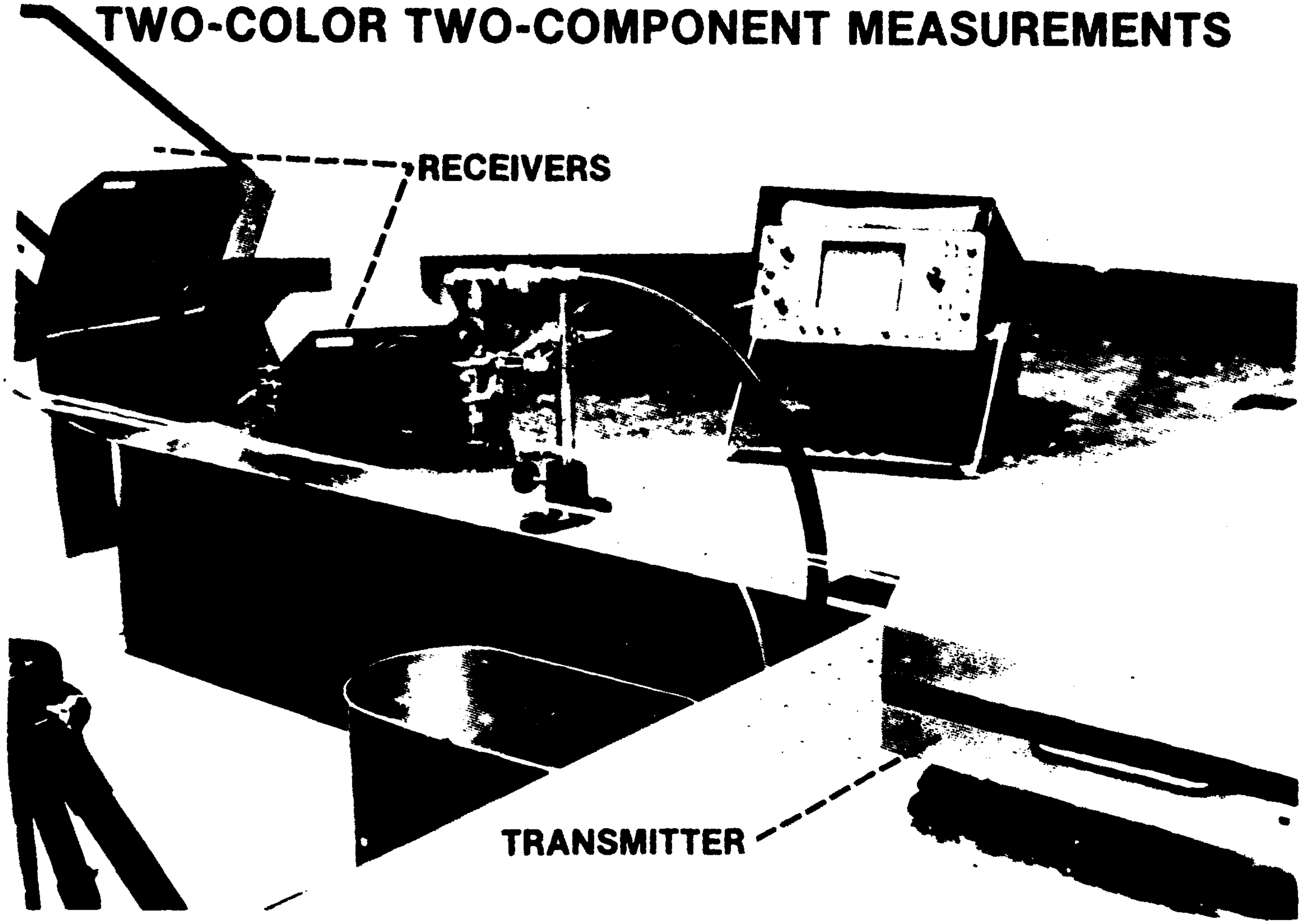
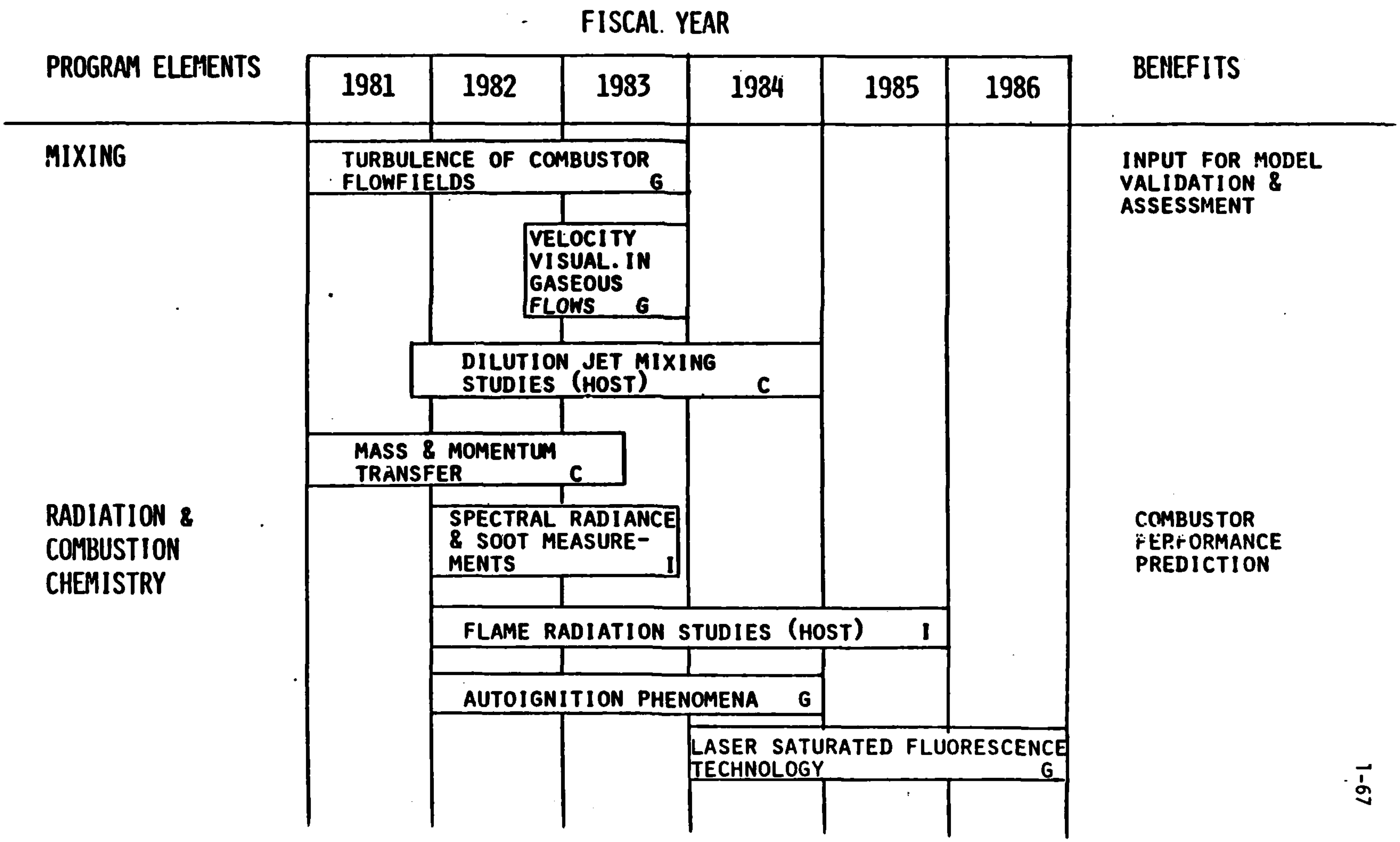
DSI EXPERIMENT CONFIGURATION
FUEL NOZZLE SPRAY CHARACTERIZATION
TWO-COLOR TWO-COMPONENT MEASUREMENTS



MODEL VERIFICATION EXPERIMENTS (2 OF 2)



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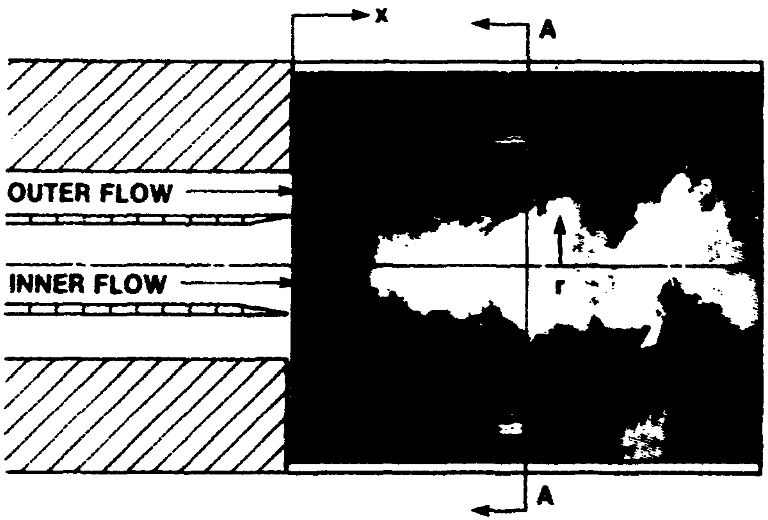
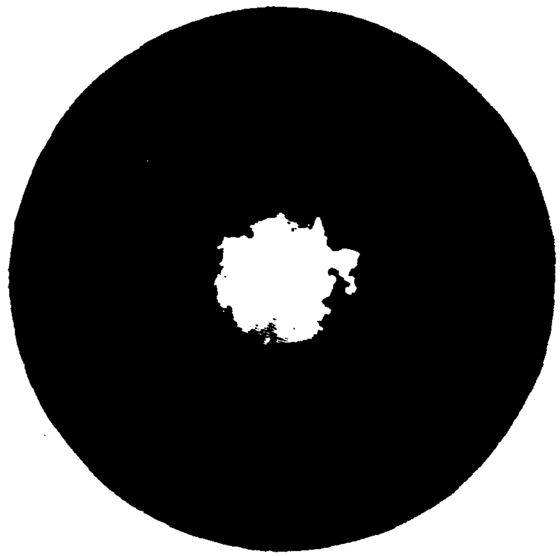
MASS & MOMENTUM TRANSFER

WATER TUNNEL EXPERIMENT



SECTION A-A



OBJECTIVE

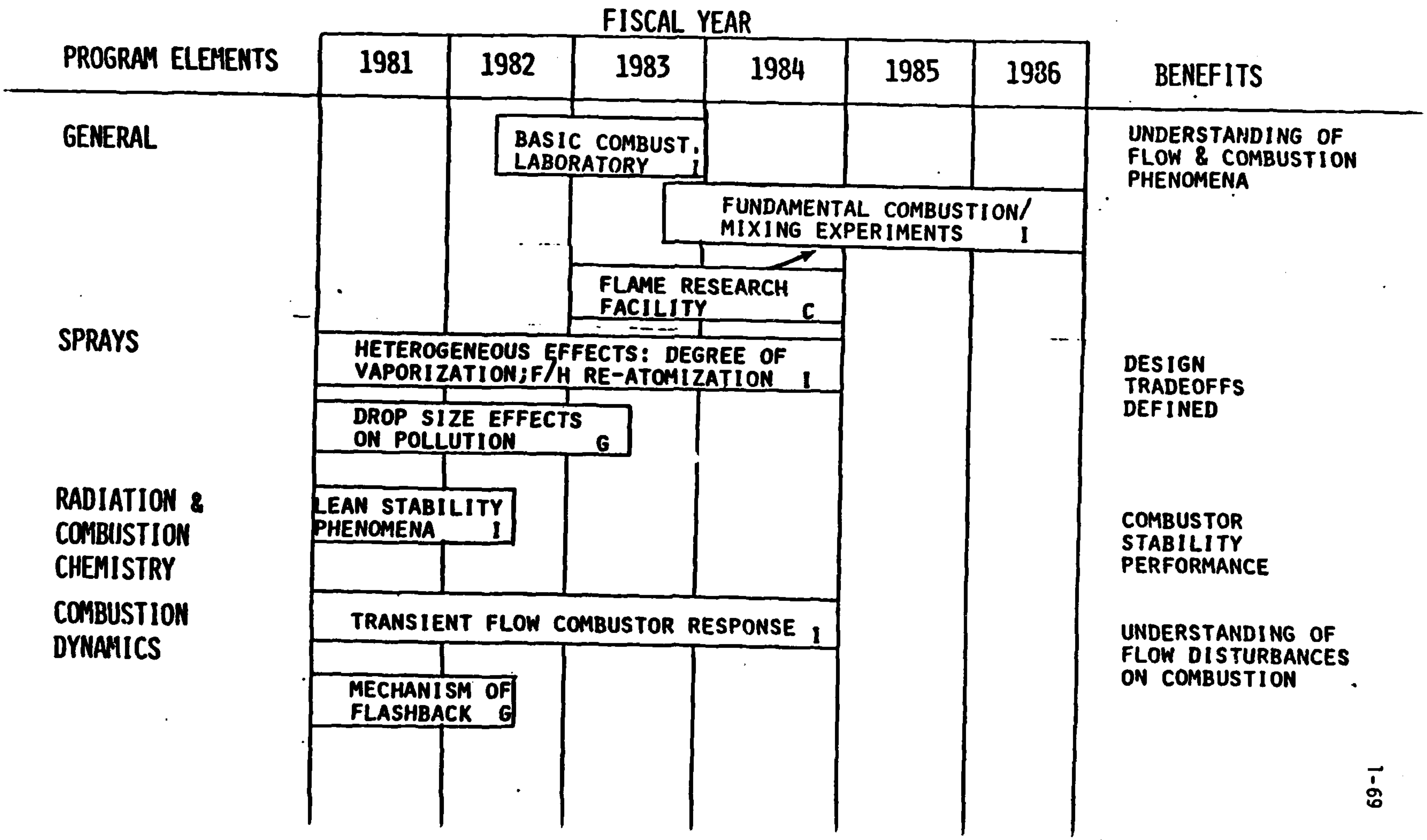
OBTAIN DETAILED DATA FOR ASSESSING CURRENT TURBULENCE MODELING CAPABILITY AND PROVIDE INFORMATION FOR ADVANCED CONCEPTS IN EDDY MASS & MOMENTUM TRANSFER

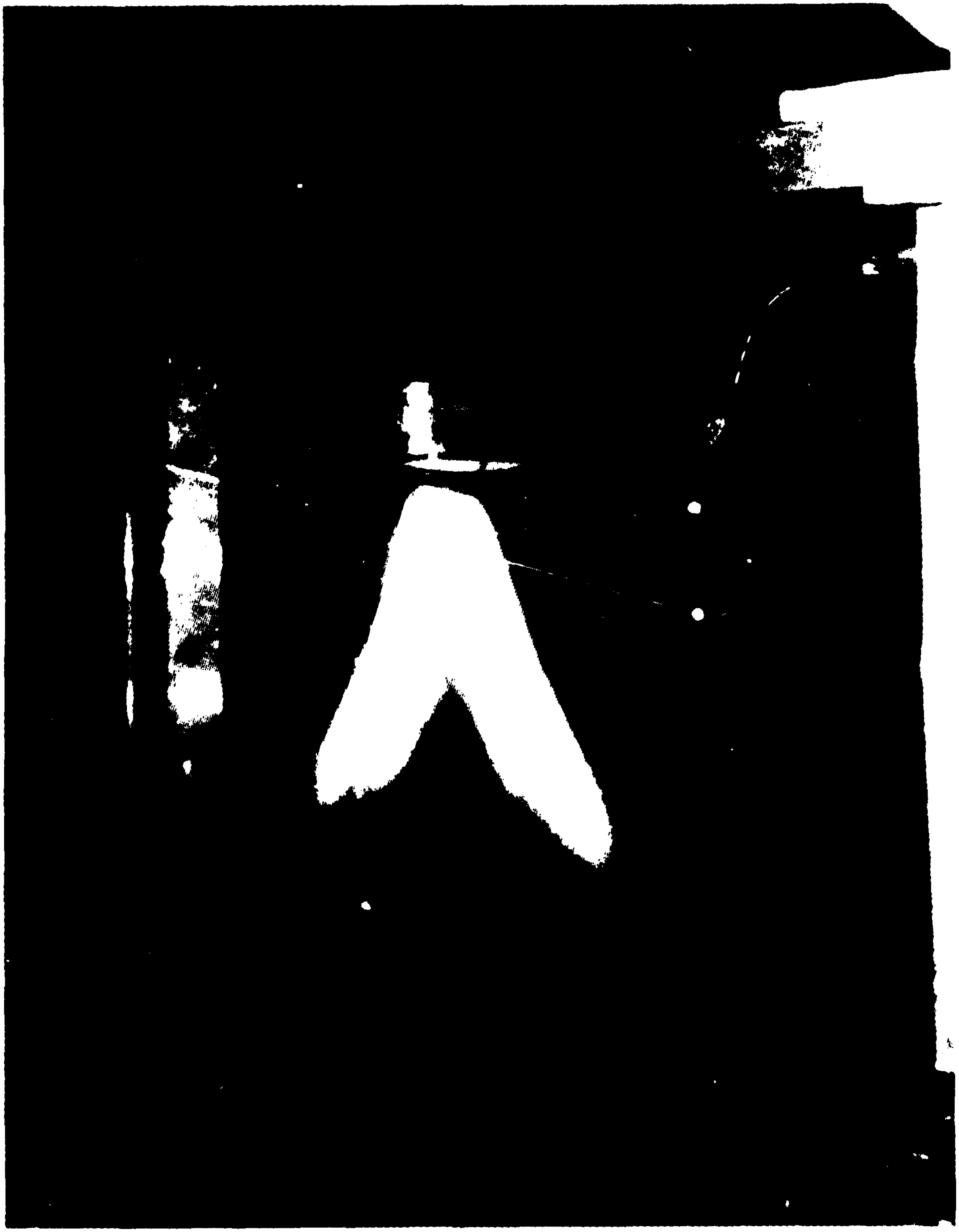
APPROACH

EXPERIMENTALLY INVESTIGATE TURBULENT MIXING IN CONFINED CO-AXIAL JET USING LASER INDUCED FLUORESCENCE AND LASER DOPPLER VELOCIMETER DIAGNOSTICS

CD-81-12780

FUNDAMENTAL COMBUSTION EXPERIMENTS



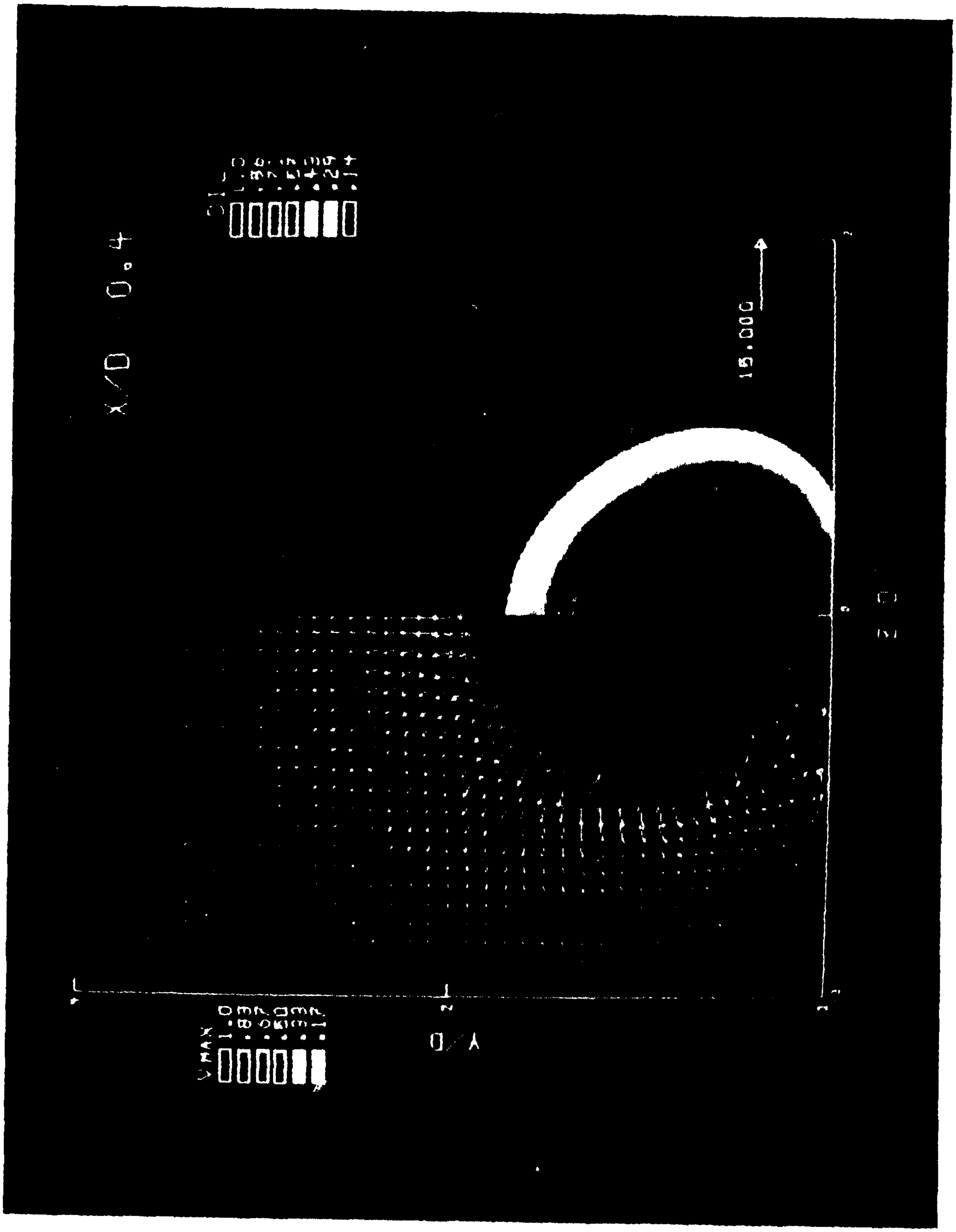


NASA
C-81-3977

ADVANCED NUMERICS

NASA

PROGRAM ELEMENTS	1981	1982	1983	1984	1985	1986	BENEFITS
GENERAL		ADVANCED GRAPHICS FOR ANALYTICAL MODELS	ADVANCED GRAPHICS FOR ANALYTICAL MODELS	ADVANCED GRAPHICS FOR ANALYTICAL MODELS I			IMPROVED SUBMODELS - USER FRIENDLY - GREATER ACCURACY - WIDER APPLICABILITY
		ERROR REDUCTION IN ANALYTICAL MODELING	ERROR REDUCTION IN ANALYTICAL MODELING	ERROR REDUCTION IN ANALYTICAL MODELING C			
MIXING			GRID PATCHING TECHNIQUES	GRID PATCHING TECHNIQUES G			
RADIATION & COMBUSTION CHEMISTRY	FAST COMPUTATIONAL KINETICS	FAST COMPUTATIONAL KINETICS	FAST COMPUTATIONAL KINETICS G				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ARMY MOBILITY ENGINE-FUELS R&D INTERFACE

S. J. Lestz

U. S. Army Fuels and Lubricants Research Laboratory

Southwest Research Institute

San Antonio, Texas

ABSTRACT

This presentation discusses the engine-fuel interface as related to present and future Army mobility equipment systems. Improved engine-fuels utilization is not only an Army/DOD objective, but a national energy goal. To achieve this goal in a most effective manner requires an interdisciplinary understanding by both fuels and engines developers. The Army is concerned with development of more fuel-tolerant engines (a long-term goal), and improved fuels' availability (a short- to long-term goal). Both problems require cooperative efforts on behalf of the engine and the fuels developers. This presentation looks at ways in which Army fuels and engines researchers interface as they work towards improved engine-fuels utilization.

ARMY MOBILITY FUELS RDTE INTERFACE

FUELS DEVELOPER
(MERADCOM)

- FUELS PROCESSING KNOWLEDGE
- FUEL PROPERTY/ COMPOSITION
- ENGINE PERFORMANCE CHARACTERISTICS
- FUTURE ENGINE FUEL REQUIREMENTS
- FUEL SPECIFICATION DEVELOPMENT

ENGINE DEVELOPER
(TACOM, AVRADCOM, & MERADCOM)

- ENGINE MODIFICATIONS
- PRODUCT IMPROVEMENTS
- FUTURE ENGINES
- MULTIFUEL REQUIREMENTS
- ENGINE SPECIFICATION DEVELOPMENT

RDTE TO IMPROVE ENGINES-FUELS UTILIZATION OF ARMY MOBILITY EQUIPMENT

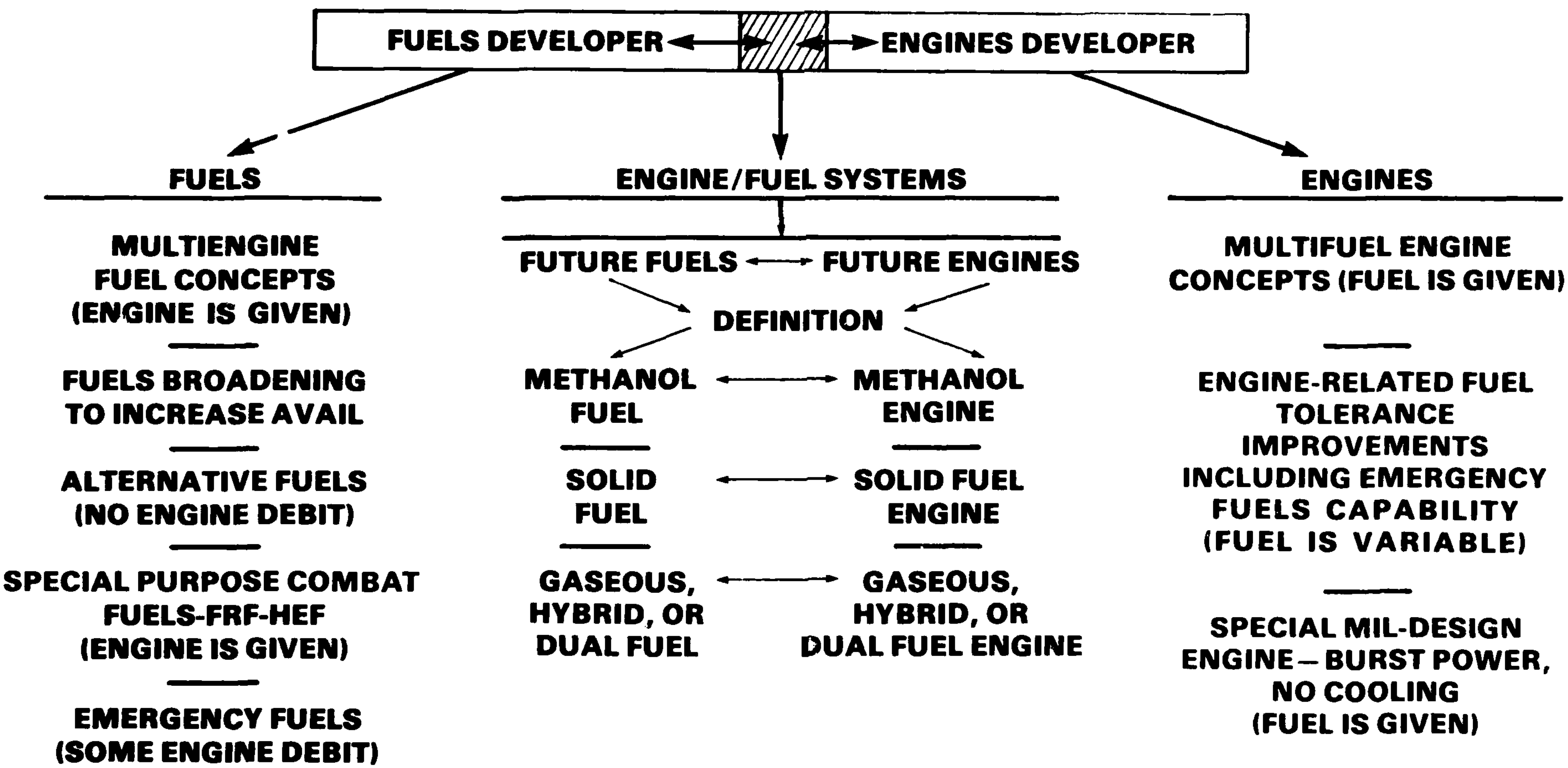
OBJECTIVE I – MAXIMIZE CURRENT AND NEAR-TERM FUELS AVAILABILITY FOR MILITARY FLEET BY:

- MODIFYING EXISTING ENGINES TO IMPROVE ECONOMY
- ESTABLISHING FUELS TOLERANCE TO ENHANCE AVAILABILITY
- DEFINING LIMITATIONS OF FUELS FOR FIELD EMERGENCY USE

OBJECTIVE II – PROVIDE MULTIFUEL ENGINE CAPABILITY FOR MILITARY OPERATION USING HIGH AVAILABILITY FUTURE FUELS BY:

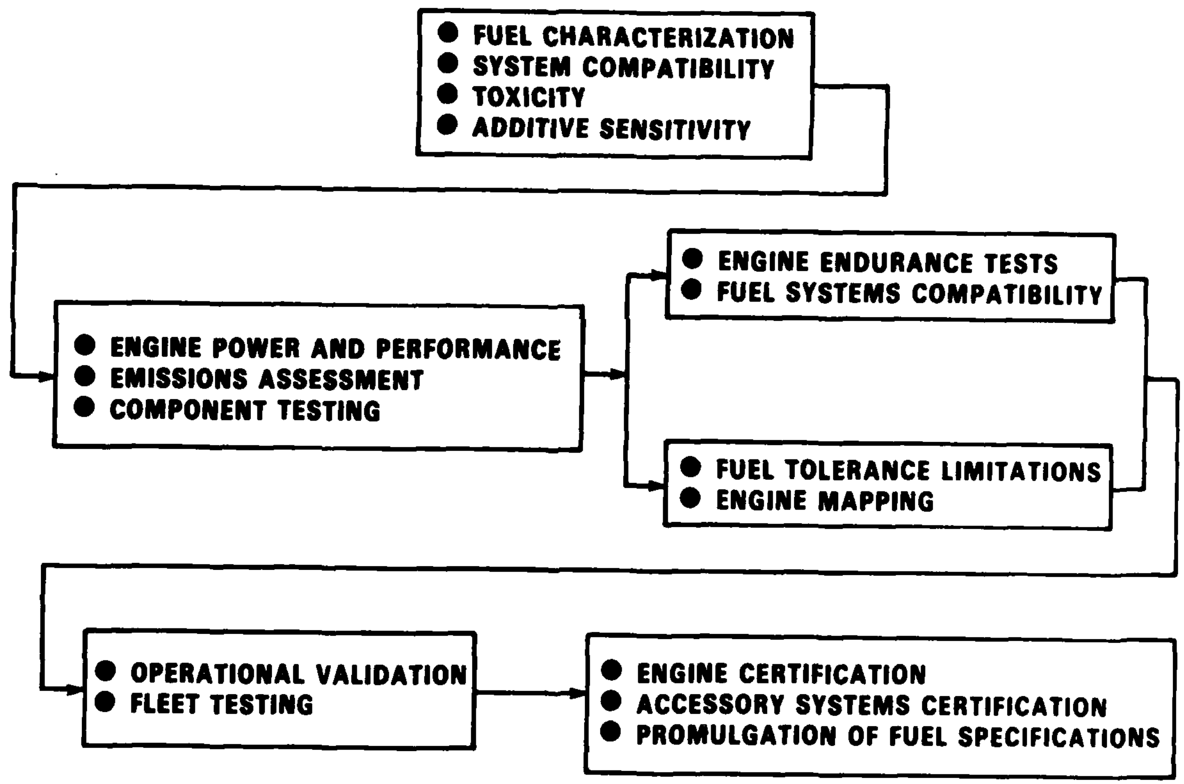
- ESTABLISHING PROTOTYPE REFEREE FUELS
- MODIFYING/REDESIGNING ENGINE AND HARDWARE FOR MULTIFUEL/MULTISOURCE FUEL CAPABILITIES

ARMY MOBILITY FUELS/ENGINES DEVELOPMENT

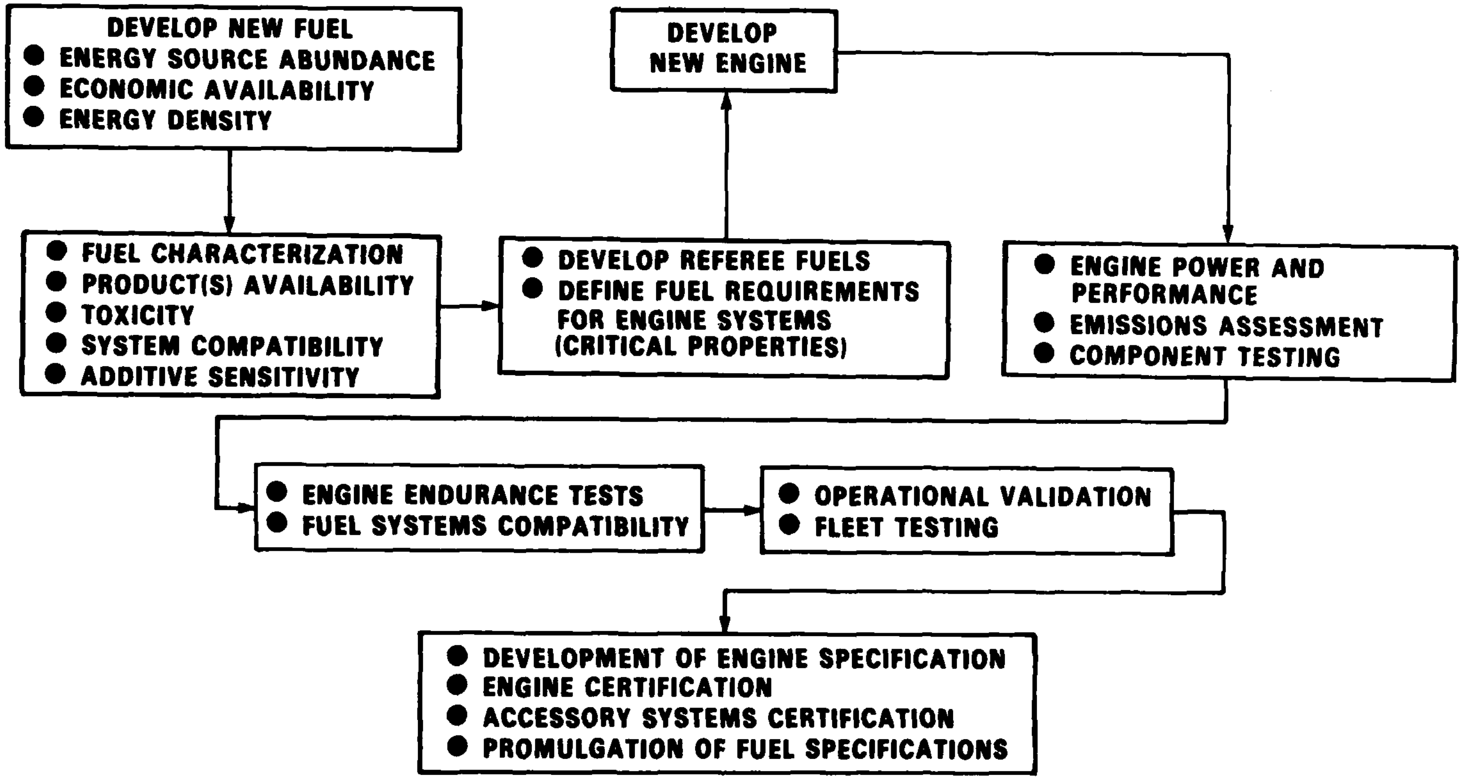


MERADCOM/AFLRL

ARMY FUEL-ENGINE DEVELOPMENT CYCLE WHERE ENGINES ARE A GIVEN

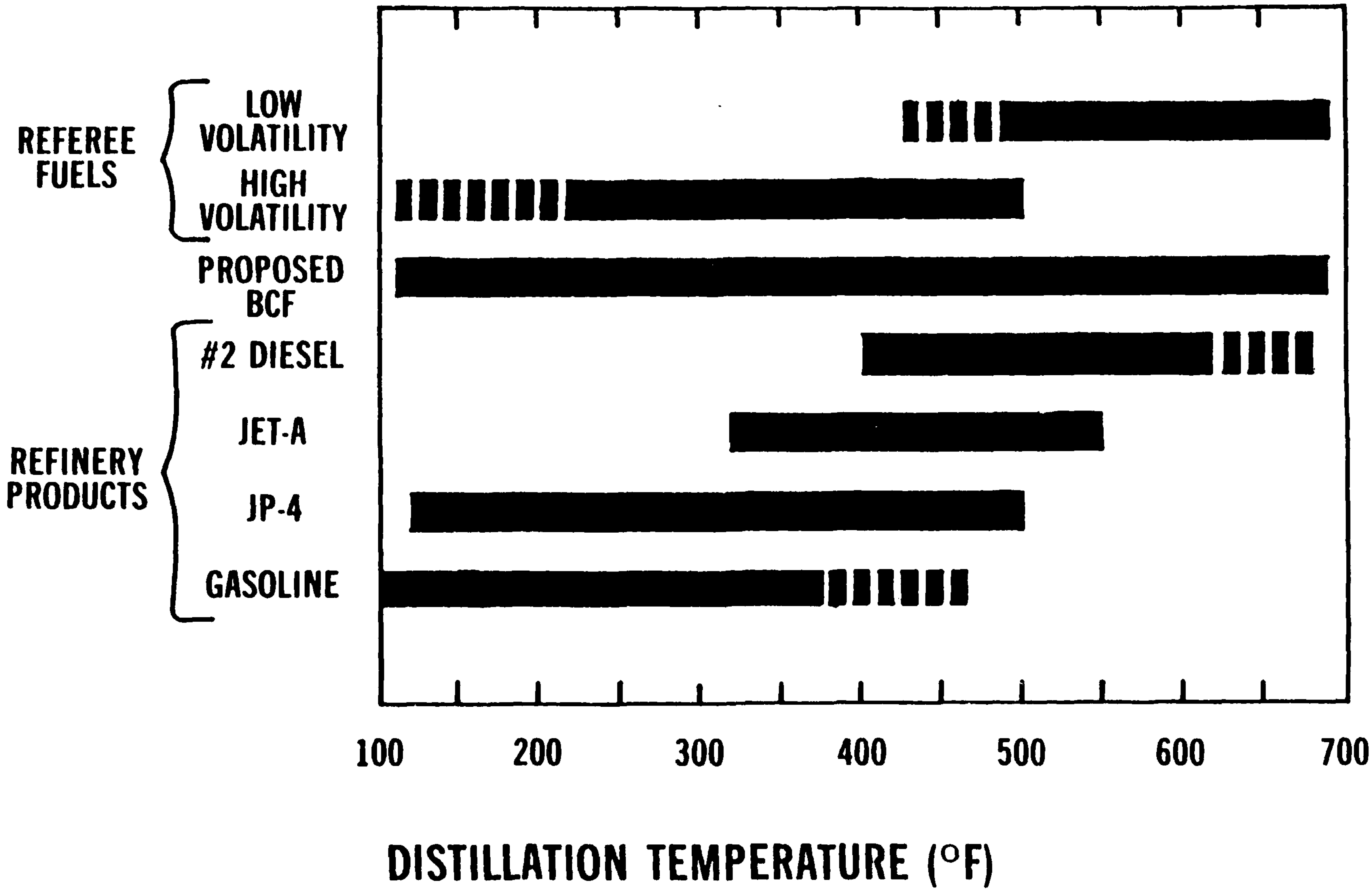


ARMY FUEL-ENGINE DEVELOPMENT CYCLE WHERE ENGINES ARE NOT A GIVEN



MULTIFUEL ENGINE DESIGN REFEREE FUELS

FUEL:	TYPE I, H. VOL.		TYPE II, L. VOL.	
	RQMTS	VALUES	RQMTS	VALUES
PROPERTIES -				
DENSITY, KG/L	0.750-.802	0.784	0.887 MIN	0.924
DISTILLATION, ^{o}C				
10%	127 MAX	103	NR	256
50%	191 MAX	164	260 MAX	296
90%	232 MAX	227	316-371	337
E.P.	288 MAX	258	NR	368
SULFUR, WT %	0.5 MAX	0.01	0.8-1.2	0.95
CETANE NO.	20-30	27.8	35 MAX	34.7
KIN. VISCOSITY cST.	0.9 MAX	0.76	4-9	3.74
CARBON RESIDUE, WT%	0.2 MAX	0.08	0.40 MAX	-



REFEREE FUELS
LOW VOLATILITY
HIGH VOLATILITY
PROPOSED BCF
REFINERY PRODUCTS
#2 DIESEL
JET-A
JP-4
GASOLINE
100
200
300
400
500
600
700
DISTILLATION TEMPERATURE (°F)

FUEL TOLERANCE EFFORTS

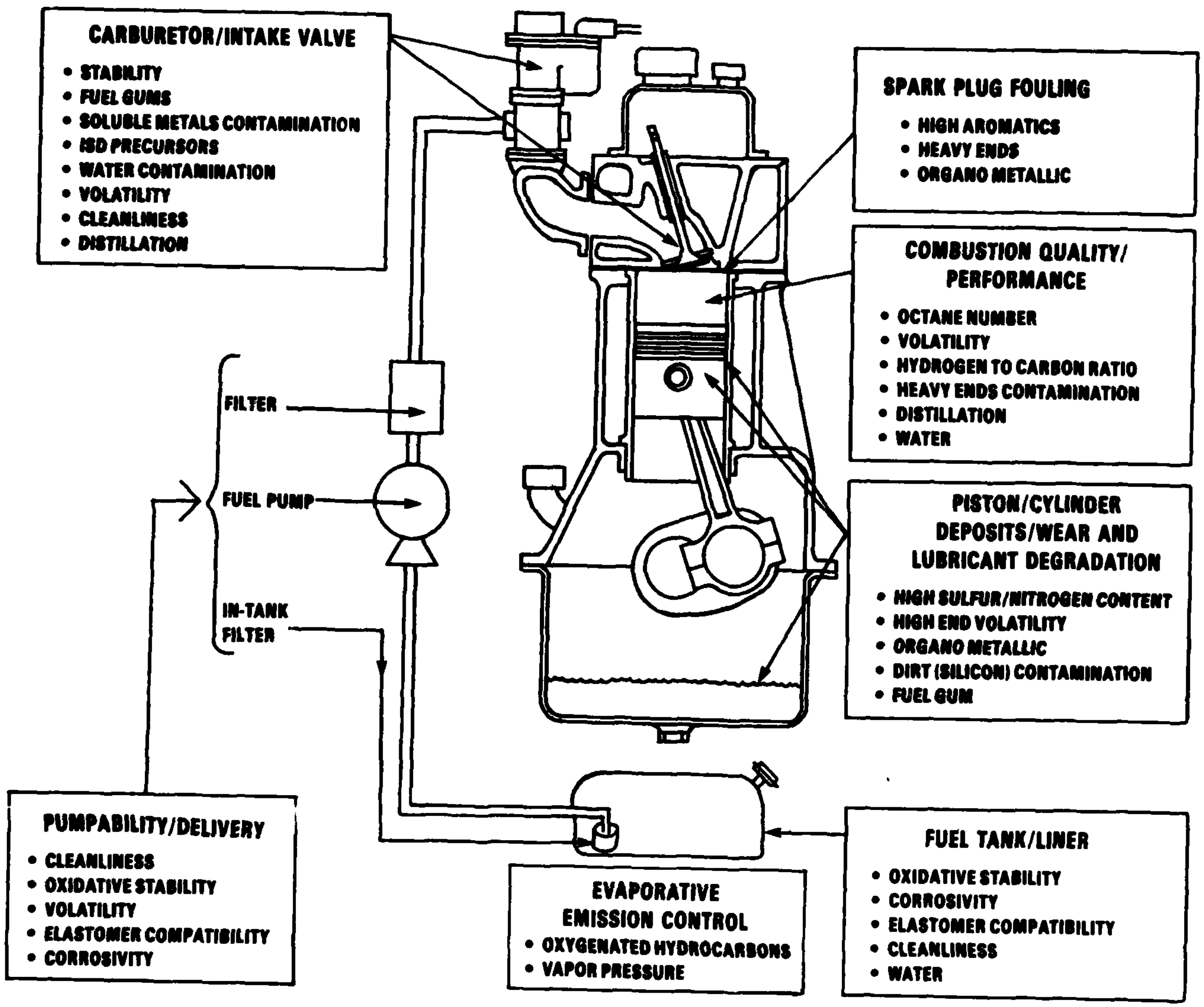
TASK	MEASURED BY
DETERMINE ENGINE PERFORMANCE PARAMETERS	● COMBUSTION EFFECTS ● POWER ● SPECIFIC FUEL CONSUMPTION ● WORK CYCLE EFFICIENCY ● EMISSIONS
DEFINE FUEL'S INFLUENCE ON ENGINE OPERATION	● POSSIBLE DERATING ● POWER IMPROVEMENT
DEFINE ENGINE-FUEL OPERATING LIMIT	● ENGINE MAPPING TO MEASURE COMBINED EFFECTS OF FUEL PROPERTIES

FUEL TOLERANCE OF ARMY ENGINES

ENGINE TYPE	FUEL SENSITIVITY RANKING*	REPRESENTATIVE ENGINE
GAS TURBINE, RECUPERATED	LEAST SENSITIVE	AVCO-LYCOMING AGT-1500
4-CYCLE, LIQUID-COOLED, DIVIDED CHAMBER, MAN MULTIFUEL	↓	CONTINENTAL LDT-465
4-CYCLE, LIQUID-COOLED, INDIRECT INJECTION	↓	CATERPILLAR 3208
4-CYCLE, LIQUID-COOLED, DIRECT INJECTION	↓	CUMMINS NHC 250
4-CYCLE, AIR-COOLED, DIRECT INJECTION	↓	CONTINENTAL AVDS-1790
2-CYCLE, LIQUID-COOLED, DIRECT INJECTION	MOST SENSITIVE	DETROIT DIESEL 6V53-T

* FUEL SENSITIVITY BASED ON COMBUSTION AND PERFORMANCE. LEAST SENSITIVE IS DEFINED AS HAVING GREATEST FUEL TOLERANCE.

ENGINE FUEL INTERFACE:SPARK IGNITION



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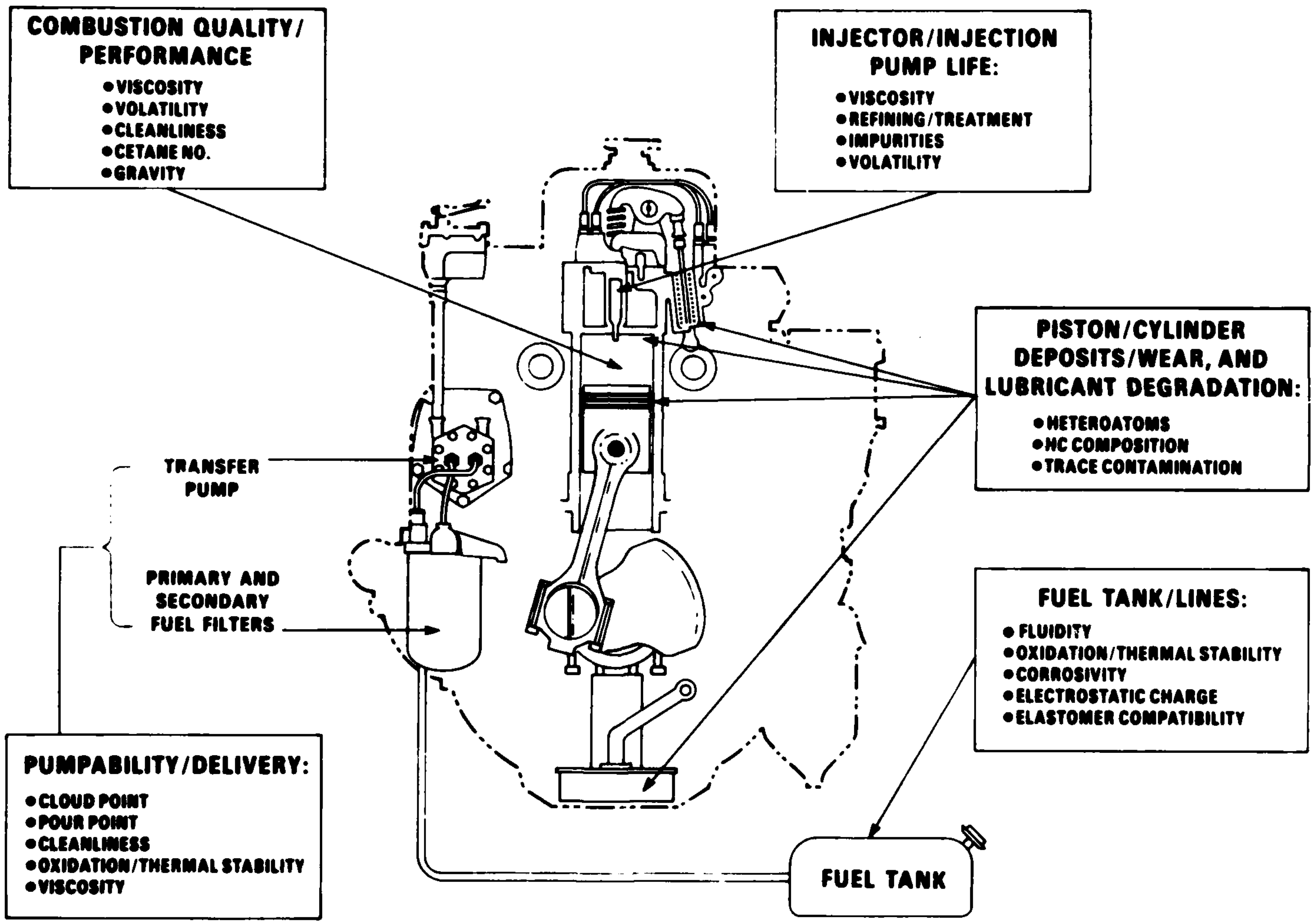
ENGINE FUEL INTERFACE: COMPRESSION IGNITION



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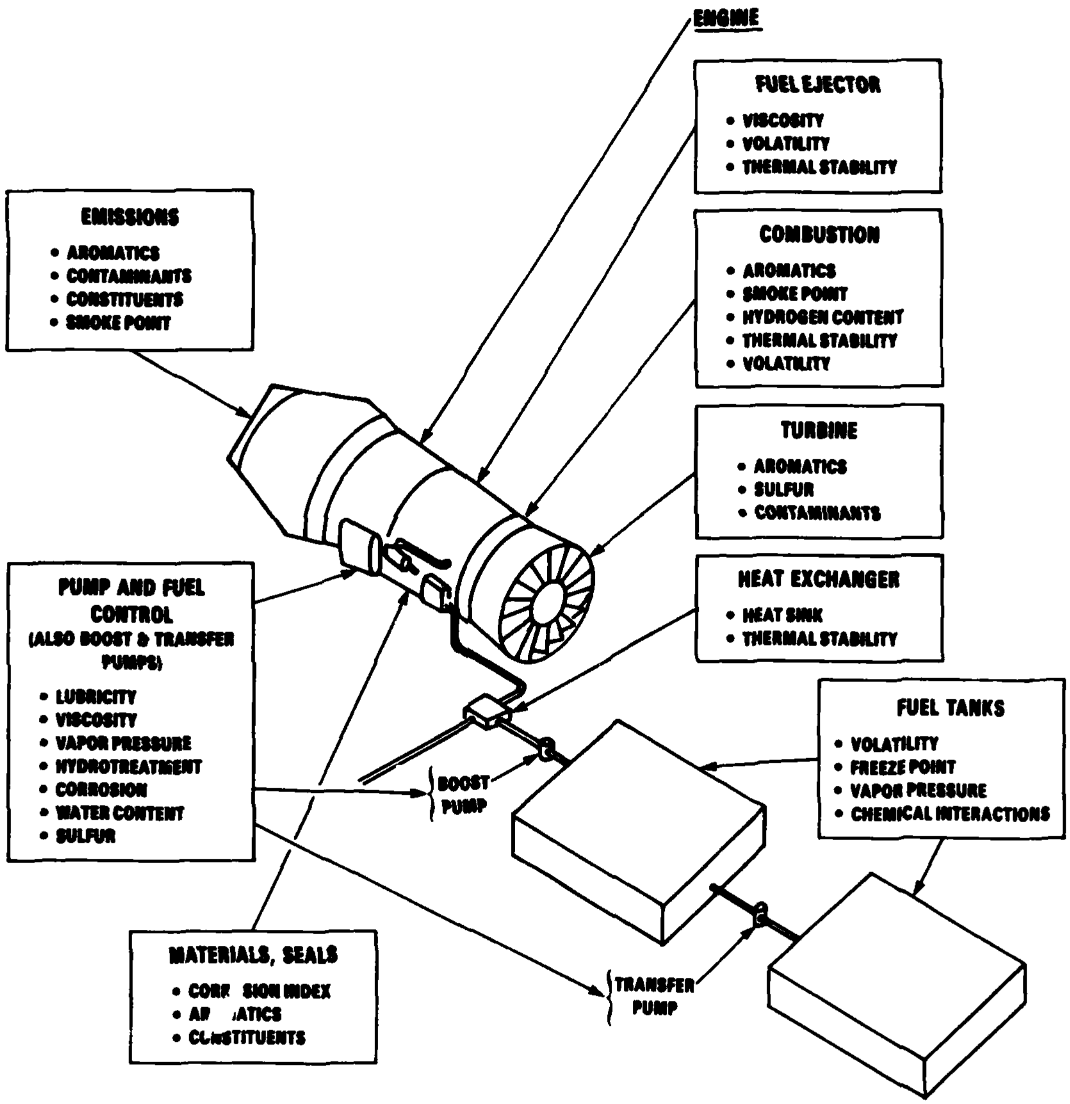
ENGINE FUEL INTERFACE: GAS TURBINE



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RESOURCES LAB

MOBILITY FUEL PERFORMANCE PROPERTIES

AREAS OF CONCERN—NEW OR MODIFIED FUELS

- **ENGINE RESPONSIVENESS**
  - **COMBUSTION QUALITY (CETANE, OCTANE, LUMINOSITY)**
  - **EMISSIONS**
- **VOLATILITY & VISCOSITY QUALITIES FOR OPERABILITY**
- **COMPATIBILITY WITH—**
  - **METALS & NONFERROUS MATERIALS**
  - **ELASTOMERS**
  - **PLASTICS**

MOBILITY FUEL PERFORMANCE PROPERTIES (CONT'D)

AREAS OF CONCERN—NEW OR MODIFIED FUELS

- **FLAMMABILITY/EXPLOSION HAZARDS**
- **POTENTIAL TOXICOLOGICAL HAZARDS**
- **MICROBIOLOGICAL SUSCEPTIBILITY**
- **IMPACT ON RAM-D FACTORS (WEAR TENDENCIES, DEPOSITS, ETC.)**
- **STORAGE STABILITY**
- **INTERCHANGEABILITY**
- **FILTERABILITY AND CLEANLINESS**

TABLE 1—Primary quality factors for mobility fuels

Fuel quality factor	Engine type: Spark-Ignition	Compression-Ignition	Turbine
Combustion	Octane No.	Cetane No.	Luminosity
Volatility	Startup and driveability	Low temp. fluidity	Nozzle operation
Cleanliness	Particulates Deposits Emissions	Particulates Water and sediment	Particulates Trace metals Surfactants Water

TABLE 2—Fuel properties needed for acceptable performance

Fuel performance required	Property controlled for given fuel type: Automotive gasoline	Diesel fuel	Turbine fuel
Handling and storage	Volatility Vapor press. Contamination (water/sedi.) Copper corr.	Flash point Viscosity Contamination (water/sedi.) Copper corr. Cloud and pour point	Flash point Viscosity Contamination (water/surfac.) Particulates Microbiological growth
Combustion	Octane No. Distillation range Gravity Hydrocarbon composition	Cetane No. Distillation range Gravity *Heat of combustion*	Luminosity Hydrocarbon *composition* Thermal stab. *Heat of* combustion
Cleanliness during use	Sulfur Existent gum Stability	Carbon resid on 10% btms Ash Sulfur Stability	Trace metals Distillation Sulfur Existent gum Stability

TABLE 3—Fuel quality affecting engine performance

Fuel development and use

- Changes in refinery feedstock/product slate
- Incorporating variable quality specification concepts
- Use of emergency fuel specification
- Use of waiver/off-specification product
- *Controlled product contamination* (i.e., blending pipe line interfaces)
- *Use of substitute fuels*

Environmental factors

- Product deterioration
- Uncontrolled product contamination
- Ground water leakage
- *Inadequate housekeeping procedures*
- Microbiological growth
- Unusual ambient temperature
- Changes in storage environment

Extracted from: "Fuel Properties Vs. Engine Performance" by M. E. LePera, Hydrocarbon Processing, January 1982.

TABLE 4—Fuel effects on spark-ignition performance

Performance problem	Probable fuel-related causes
Excessive engine wear	High sulfur content Dirt (silicon) contamination
Poor combustion	Inadequate octane number Heavy ends contamination Preformed gum impurities
Poor cold starting	Improper volatility control Water contamination
Hot fuel problems	Improper volatility control
Carburetor/induction *system fouling*	Heavy ends contamination High sulfur content Preformed gum impurities Soluble metal contaminants
Filter plugging	Water contamination Dirt (silicon) contamination
Spark plug fouling	High aromatics content

TABLE 5—Fuel effects on compression-ignition performance

Performance problem	Probable fuel-related causes
Poor combustion, smoking	Low cetane number Water contamination Improper cloud point *Lighter/heavier fuel contamination*
Excess cylinder wear	Fuel dilution High sulfur content Dirt (silicon) contamination
Injector nozzle plugging/wear	*Soluble metal contaminants* Heavy end impurities Preformed gum impurities
Injector pump *fouling/sticking*	High sulfur/hetero-atom content Heavy ends contamination Gasoline contamination Low fuel viscosity
Filter plugging	Water contamination Fuel impurities Improper cloud point Thermally-reactive hydrocarbons
Excess engine deposits	Heavy ends contamination Low cetane number High sulfur/hetero-atom content

TABLE 6—Fuel effects on turbine performance

Performance problem	Probable fuel-related causes
Poor combustion	Low luminometer number Low smoke point High aromatics content High carbon residue values *Heavier fuel contamination*
Excess liner/blade deposits, hot end distress	High fuel viscosity Low hydrogen content High sulfur/hetero-atom content High aromatics content Soluble metal contaminants
Nozzle plugging/wear	High particulate contamination Soluble metal contaminants Heavy end impurities Marginal thermal stability High sulfur content
Fuel control system malfunction	High sulfur/hetero-atom content Heavy ends contamination Thermally-reactive hydrocarbons Low fuel viscosity *Marginal lubricity*
Filter plugging	Water contamination Surfactant contamination Microbiological growth Fuel impurities Improper freeze point Thermally-reactive hydrocarbons

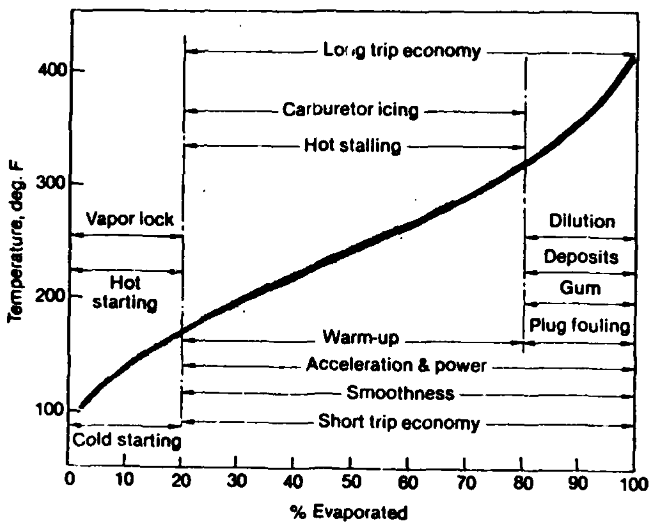

Fig. 1—Relation of gasoline distillation range to engine performance.

TABLE 7—Fuel tolerance of Army engines (Listed in order of decreasing tolerance, i.e., increasing order of sensitivity)

Engine type	Representative engine
Gas turbine, recuperated	AVCO-Lycoming AGT-1500
4-Cycle, liquid-cooled, divided chamber, multifuel	Continental LDT-465
4-Cycle, liquid-cooled, indirect injection	Caterpillar 3208
4-Cycle, liquid-cooled, direct injection	Cummins NHC 250
4-Cycle, air-cooled, direct injection	Continental AVDS-1790
2-Cycle, liquid-cooled, direct injection	Detroit Diesel 6V53-T

TABLE 8—Unique requirements for Army fuels

- Survivability by reducing or eliminating fuel fire hazards
- Commonality of fuels: NATO standardization, interoperability
- Enhanced storage stability
- Multipurpose use—low and high ambient temperatures
- Specific fuel inhibitors
- Increased combustion efficiency and high energy potential
- Potential for emergency fuel applications

Extracted from: "Fuel Properties Vs. Engine Performance" by M. E. LePera, Hydrocarbon Processing, January 1982.

AD-A122 843 ENGINES/FUELS WORKSHOP 6-8 DECEMBER 1982 SAN ANTONIO TEXAS(U) SOUTHWEST RESEARCH INST SAN ANTONIO TX ARMY FUELS AND LUBRICANTS RESEARCH LAB D M MANN ET AL. 1982 2/3

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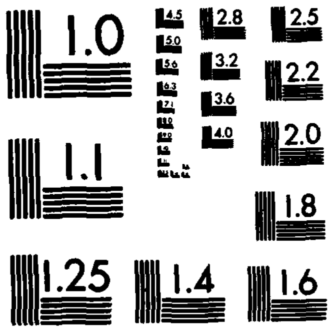


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

PROBLEM | **RESULT OF** | **CONTRIBUTING FACTORS**

- INADEQUATE LOW TEMPERATURE OPERABILITY
  - FUEL
    - Fuel Composition (i.e., Paraffin Content)
    - Fuel Properties (i.e., Viscosity, Volatility)
    - Contaminants (i.e., Dirt, Water)
    - Fuel Deterioration (i.e., Gums, Insolubles)
    - Fuel Mis-application (i.e., Inadequate Cloud Pt.)
  - EQUIPMENT
    - Engine (i.e., Diesel vs Turbine)
    - Fuel System Design (i.e.,Recirculation, Line Locations)
    - Fuel Tank Design/Configuration (i.e., Metal, Elastomers, Plastic)
    - Fuel Tank Sump Contaminants (i.e., Water)
    - No. and Type of On-Board Fuel Filters
    - Fuel Level in Tank (i.e., Half-Filled, Full)
    - *Environment (i.e., Outdoor, Shed)*
    - Engine/Fuel System Maintenance Needed (i.e., Condition of Filters)
    - Engine Oil Condition and Grade
  - USER PRACTICE
    - Vehicle Maintenance Procedures
    - Rotation of Fuel Stocks (i.e., Product Scheduling, Summer vs Winter)
    - "Topping-Off" Procedures
    - Use of F/S Units for Fuel Dispensing
    - Fuel Procurement Practices (i.e., How Purchased)
    - Equipment Use Rate (i.e., Intermittant, Full-Time)
    - Product Turnover Rate at Dispensing Pumps
    - Poor Housekeeping Practices
    - Unauthorized Product Substitutions (i.e., Fuel Oil)
    - Unauthorized Use of Proprietary Additives (i.e., Flow Improvers)
    - Inadequate Vehicle Preparation (i.e., Radiator Shutters, Line Heaters)

Session 2
ARO COMBUSTION RESEARCH

Chairman: D. M. Mann
U. S. Army Research Office
Research Triangle Park, NC

ABSTRACT

TRANSIENT CATALYTIC COMBUSTION

Richard O. Buckius
Department of Mechanical and Industrial Engineering

Richard I. Masel
Department of Chemical Engineering

University of Illinois at Urbana-Champaign
Urbana, IL. 61801

Considerable attention has been recently given to the use of catalysts in diesel engines. The objectives of the present effort are to determine kinetic data for hydrocarbon fuels for various catalysts and to model heterogeneous reactive fluid mechanics from a transient viewpoint. Experimental data obtained to date indicates that the kinetics of formaldehyde can be modeled as decomposing into CO and H_2 on the surface of the catalyst and then CO and H_2 burn as though no formaldehyde is present. The data for the formaldehyde can be fit by a mechanism where the rate determining step is the dissociative adsorption of formaldehyde onto the catalyst. The analytical effort to date addresses the transient oxidation of CO and H_2. The heterogeneous reactive flow over a flat plate subject to various boundary conditions have been considered. Both "light-off" and "shut-off" solutions have been evaluated. Results of these transient calculations will be presented and discussed.

Basic Studies of Catalytic Combustion at UTRC

P. J. Marteney
United Technologies Research Center
East Hartford, CT

ABSTRACT

The catalytic combustion program at UTRC is aimed at determining specific surface reaction rates of hydrocarbon fuels in the catalytic combustor. The usually-competitive, gas-phase reactions are suppressed by a low reaction temperature. The surface reactions, plus transport of heat and mass, are treated in an analytical model. Studies to date have yielded the reaction rate of CO (which is an intermediate in the hydrocarbon oxidation) and the rates of reaction of a number of lighter hydrocarbons. Current emphasis is on the system of two-fuel mixtures and on mixed-component surfaces such as platinum-family metals supported on rare earth oxides. An important finding in two-fuel mixtures is that methane, which is usually very slow to react, is substantially oxidized in mixtures of methane and propylene or ethylene.

CATALYTIC COMBUSTION PROGRAM

- Determine fundamentals of catalytic surface reactions for practical fuels
- Use simple experimental system with flexibility in operation
- Combine experiments with analytical model to determine reaction rates

CURRENT STATUS OF PROGRAM

- Developed method for obtaining rates
- Rates for CO determined
- Rates for single fuels determined
- Tests with mixed fuels in progress
- Interaction of NO under investigation
- Surfaces varied

FEATURES OF EXPERIMENTS

- Argon dilution reduces temperature rise, suppresses homogeneous reactions
- Ignition not sensitive to dilution
- Reaction of CO studied separately, rate folded into fuel kinetics

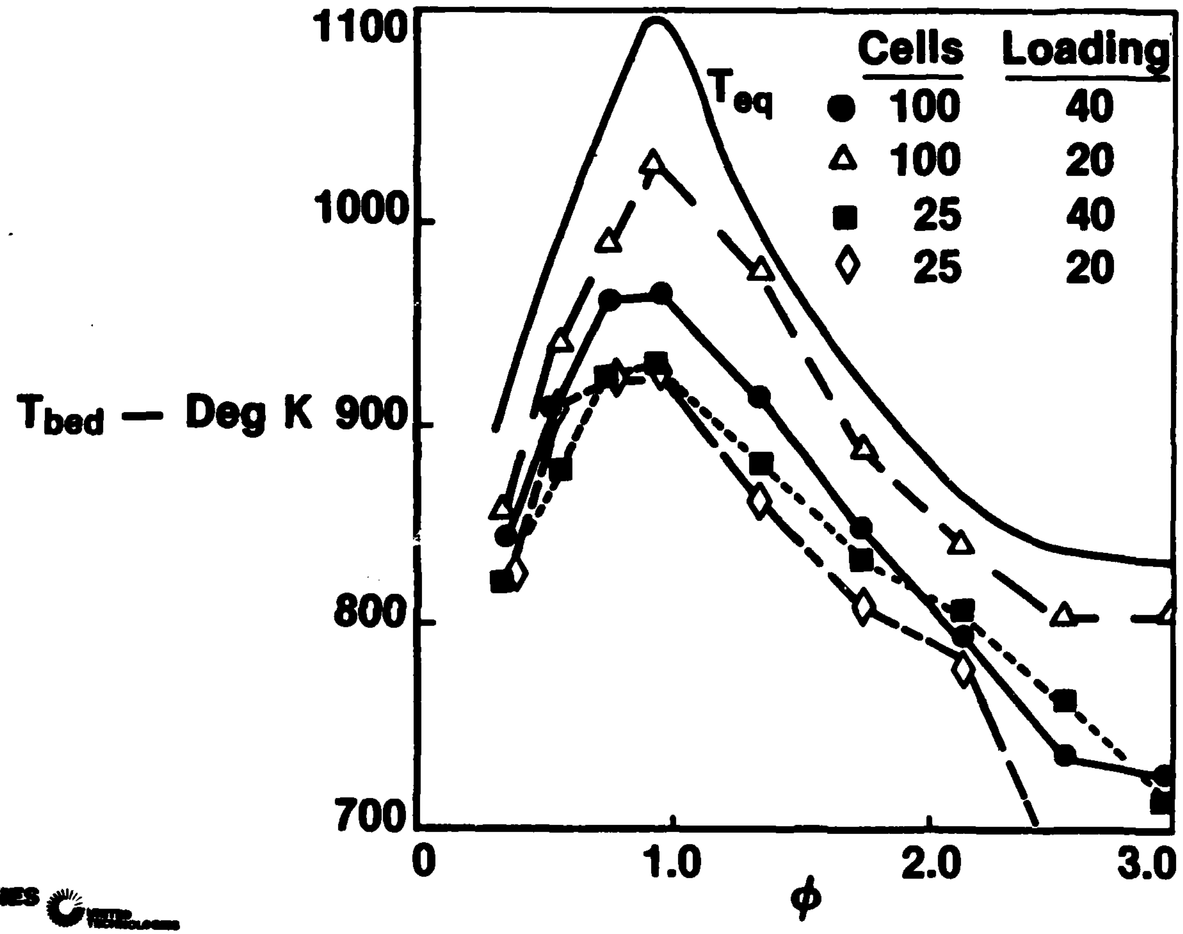
ANALYTICAL MODEL

- Parallel, global reactions in gas and on surface
- Homogeneous rates from literature
- Treat heat and mass transfer, use real properties of all species
- Determine rates in form $\alpha\ (T)^n \exp E/RT$

TEMPERATURE RISE IN CO/O_2/ARGON

Platinum on Cordierite

T_{in} — 548K



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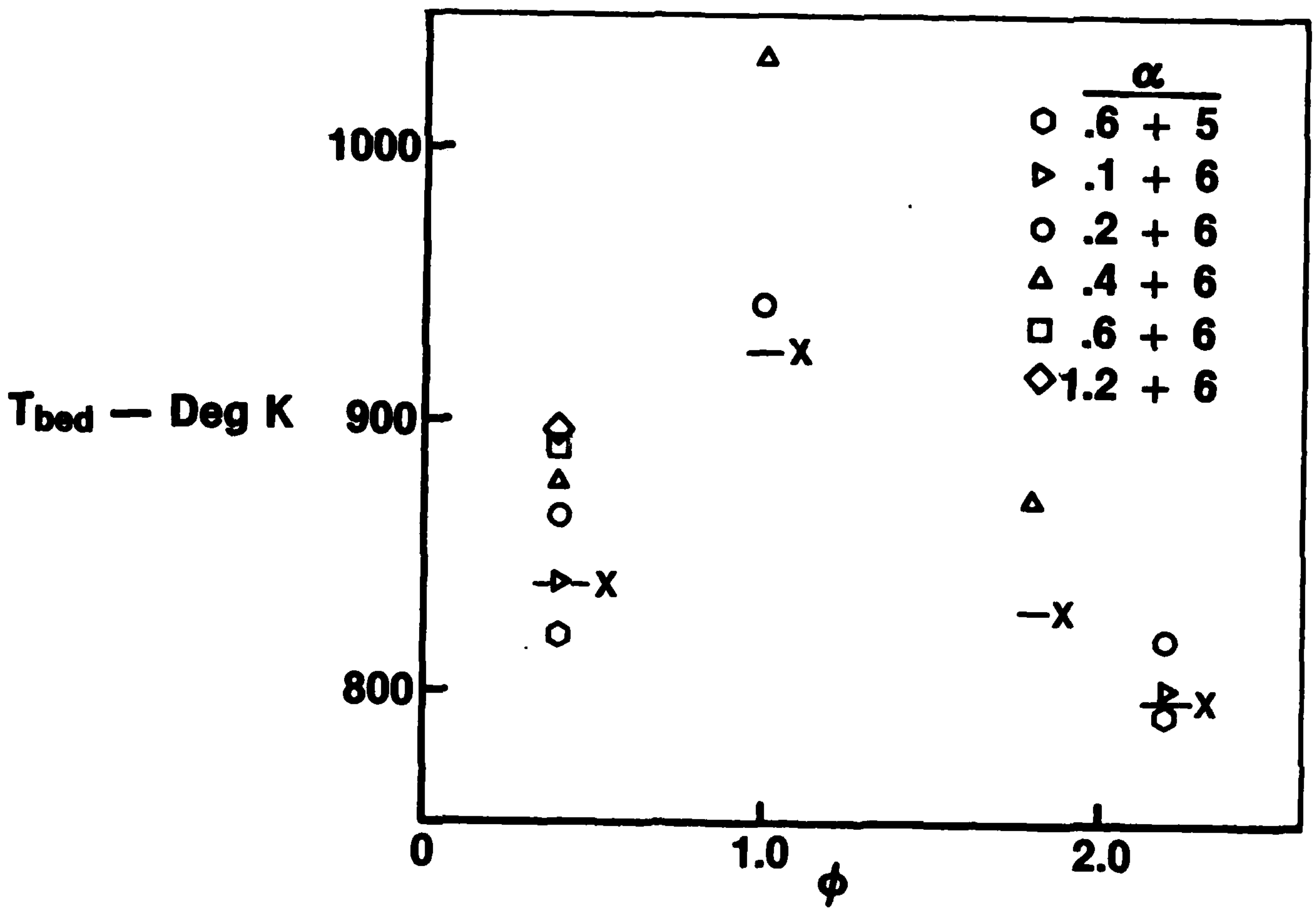
82–10–118–8

SEARCH FOR CO RATE FACTOR IN 50/20 CATALYST

E = 1.7 + 4 Kcal/mole



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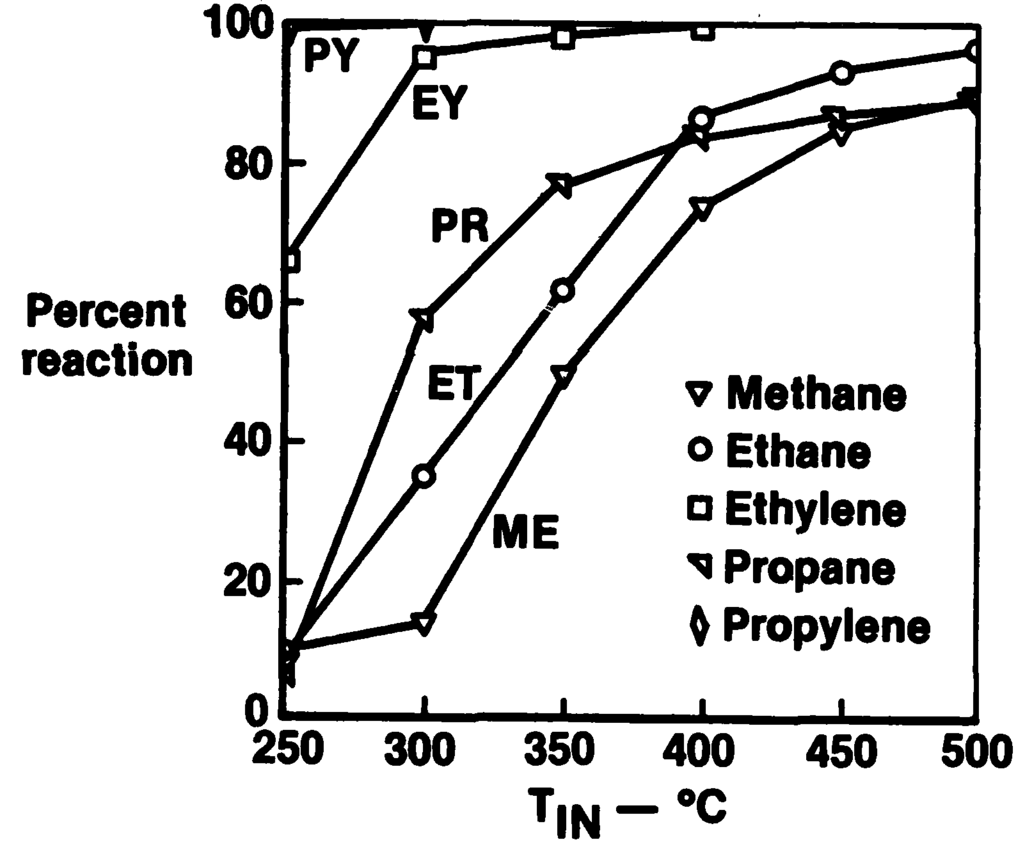
REACTION OF FUELS IN CATALYTIC COMBUSTOR



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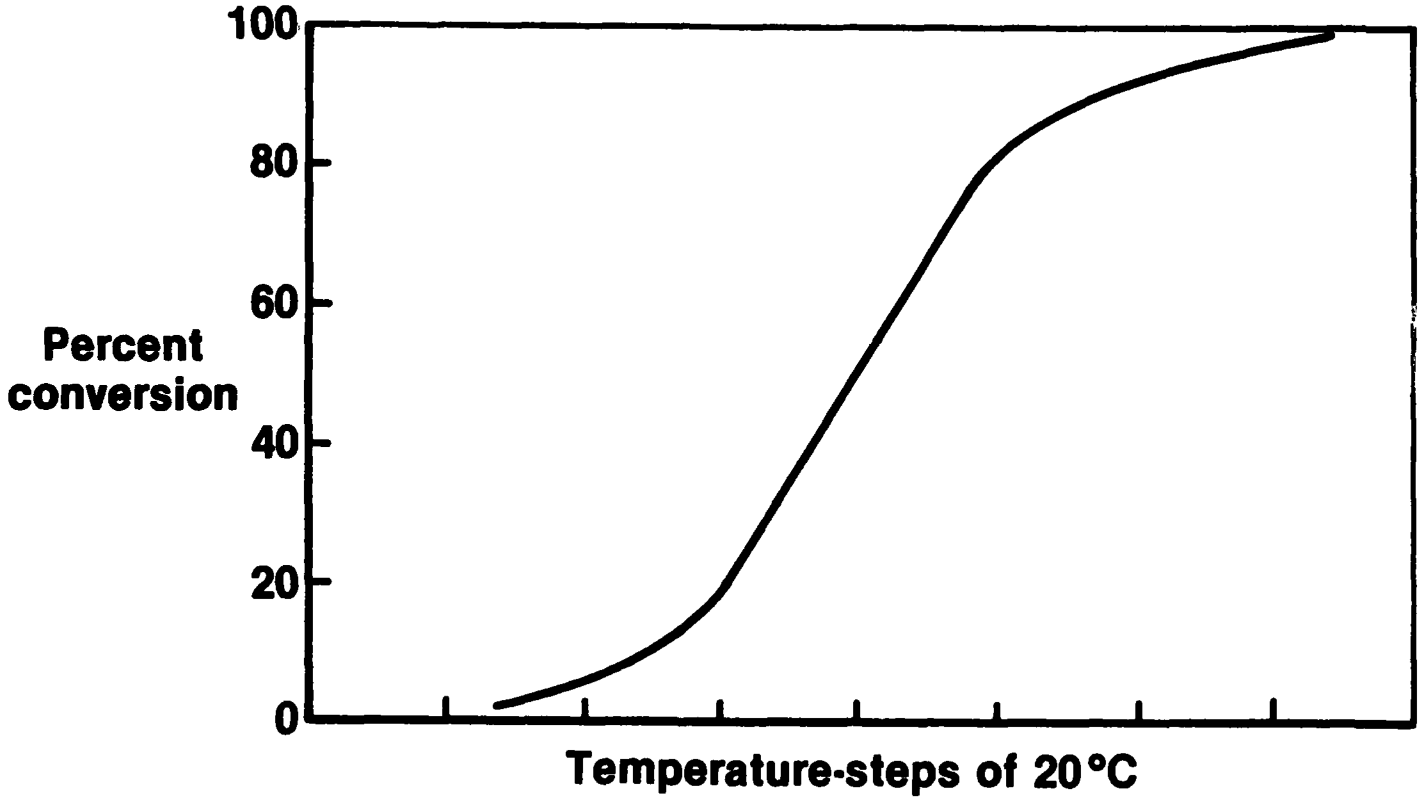
"UNIVERSAL" H/C CURVE



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ACTIVATION ENERGIES FOR H/C REACTION

Species	UTRC	Wise	Nobe
Me	20		23
Et	15	27	26
Ey	5		18
Pr	9	17	17
Py	5		17

RA465TX.002

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FUTURE STUDIES

- Obtain rates for mixed fuels, especially active/inactive pairs
- Continue tests with NO, emphasize near-stoichiometric regime
- Examine surface as a function of reaction conditions
- Use mixed-component surfaces?

TURBULENCE-COMBUSTION INTERACTIONS IN LAMINAR AND TURBULENT PREMIXED METHANE-AIR V-FLAMES

Tau-Yi Toong

Massachusetts Institute of Technology

The main objective of this study is to examine the mechanisms of turbulence-combustion interactions in premixed V-flames stabilized behind a cylindrical flameholder. Instantaneous temperatures have been measured across the flame brush by the use of 25 μm-diameter Pt/Pt-10% Rh thermocouples at different equivalence ratios and different distances from the flameholder. Turbulence-generating grids of different mesh size have also been used in order to investigate the effects of turbulence scale and intensity.

As the thermocouple is moved across the flame brush from the unburned side, temperature fluctuations start to appear with accompanying increase in the mean temperature. Within the flame brush, fluctuations of larger amplitudes and higher frequencies are observed. In the burned gases, however, fluctuations are essentially absent, implying the importance of chemical reaction rate within the reaction zone in triggering and sustaining these fluctuations.

By the use of two thermocouples spatially separated at a fixed distance, it is possible to detect the movement of the flame brush at rather low frequencies. This movement could be due to the presence of large-scale eddies or wrinkling, resulting possibly from hydrodynamic instability.

The presence of turbulence-generating grids at the burner exit leads to large amplitudes of the high-frequency fluctuations within the flame brush. The main difference between laminar and turbulent flames seems to be in the relative amplitudes of these fluctuations. This effect is more pronounced with coarser mesh size of the turbulence-generating grids.

Near the flameholder, the amplitudes of the temperature fluctuations across the flame brush are rather small. As the observation station is moved farther downstream, the flame brush becomes thicker with accompanying increase in the amplitudes, suggesting the development of instabilities due to chemical reaction within a flame kernel as it moves downstream from the recirculation zone behind the flameholder. This effect becomes more significant as the equivalence ratio approaches the stoichiometric value.

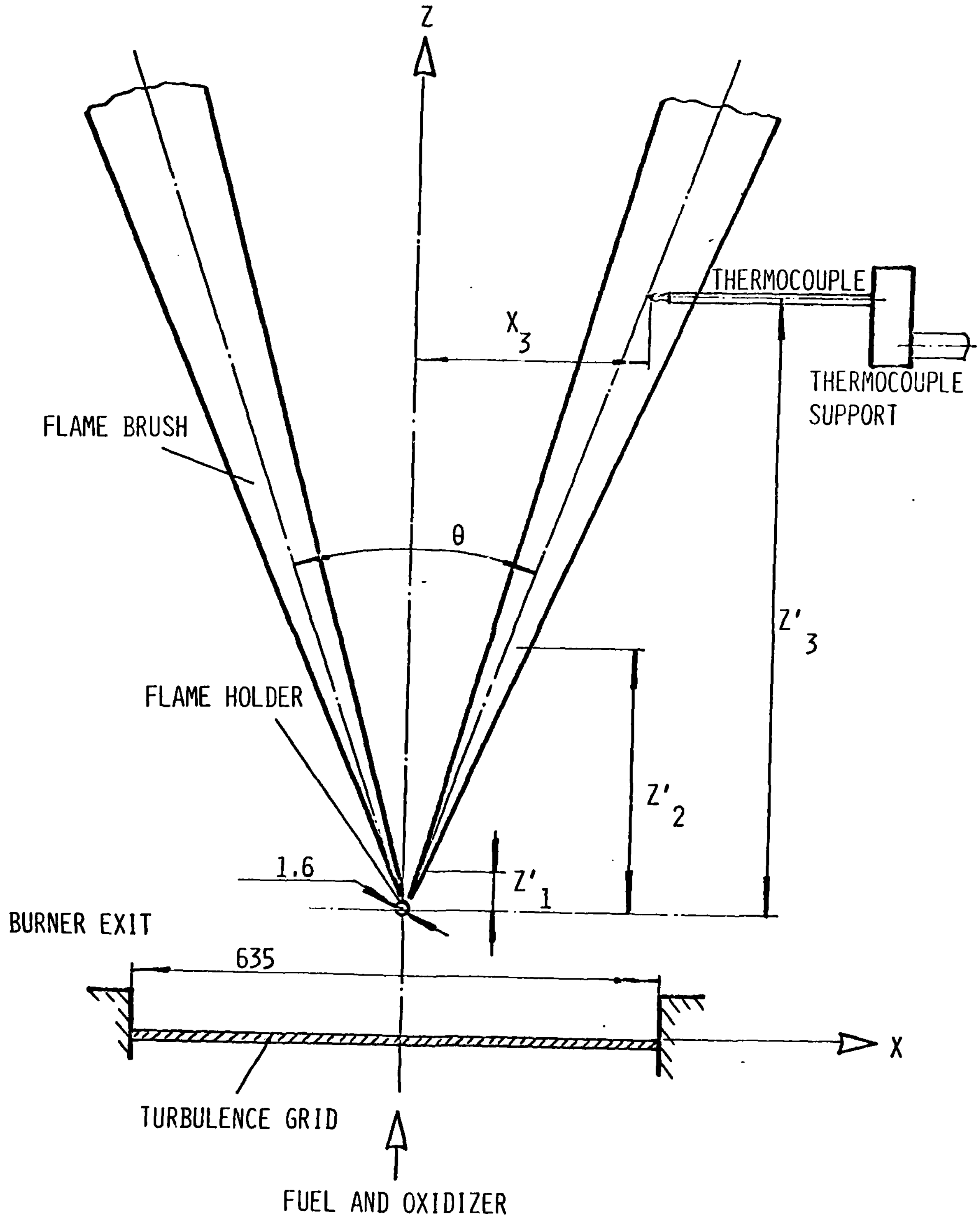
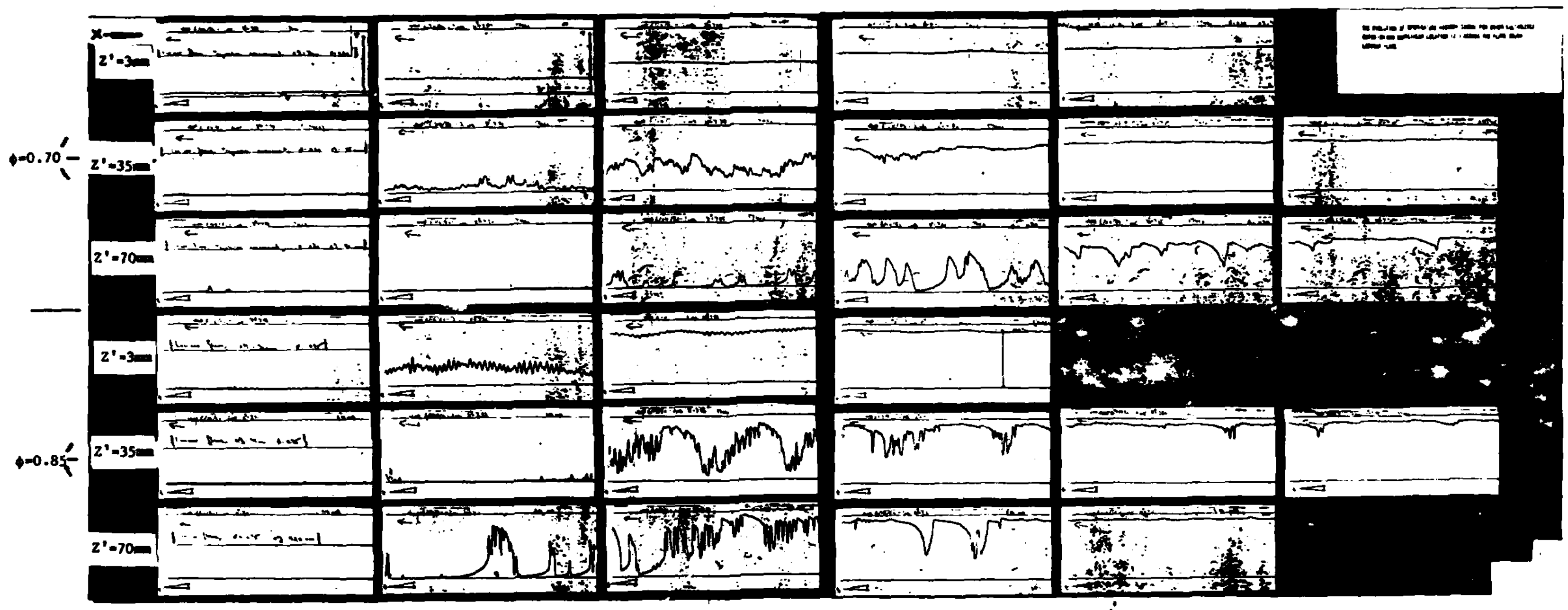
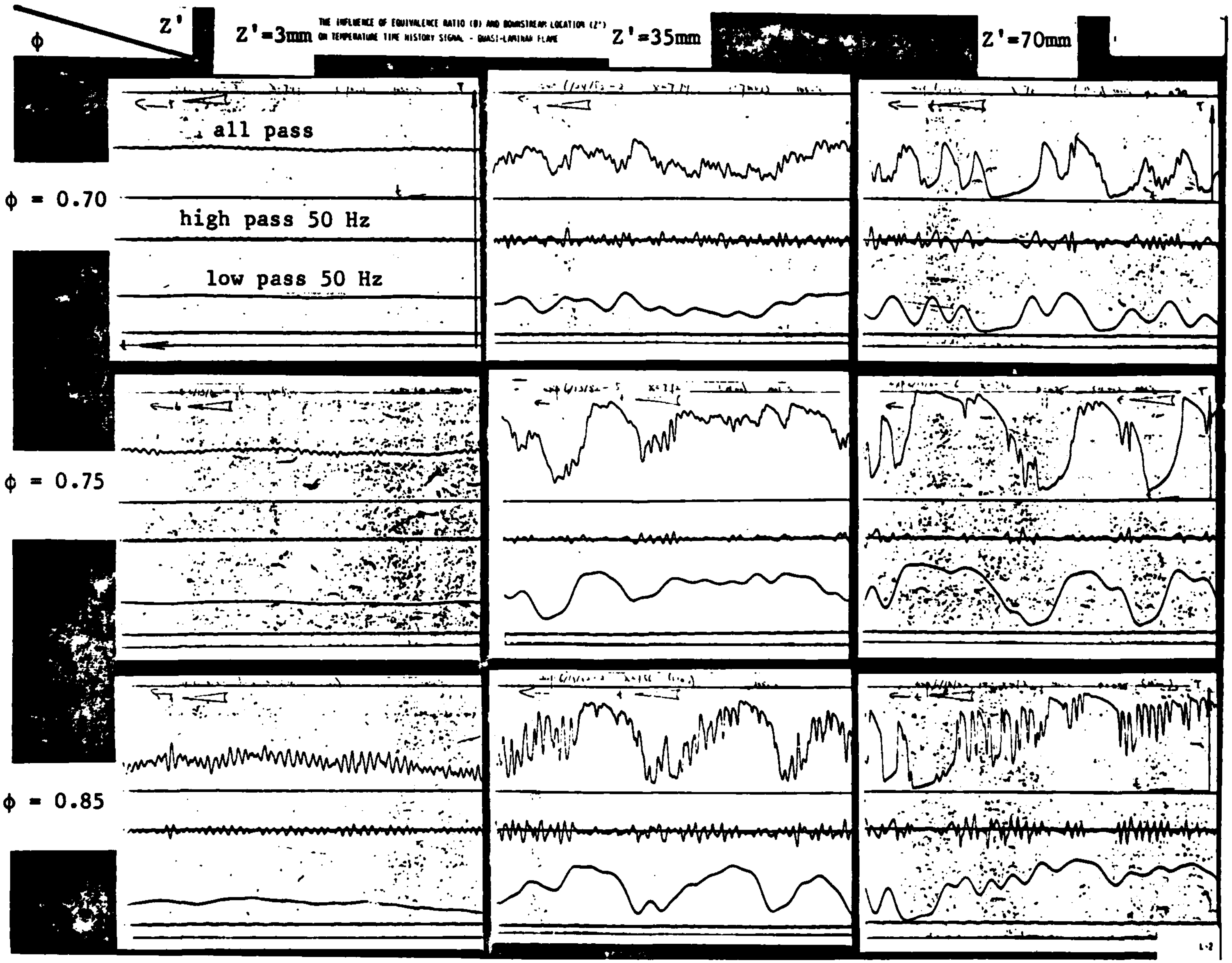

Z
THERMOCOUPLE
X
3
THERMOCOUPLE
SUPPORT
FLAME BRUSH
θ
Z'
3
FLAME HOLDER
Z'
2
1.6
Z'
1
BURNER EXIT
635
X
TURBULENCE GRID
FUEL AND OXIDIZER

Fig. 1

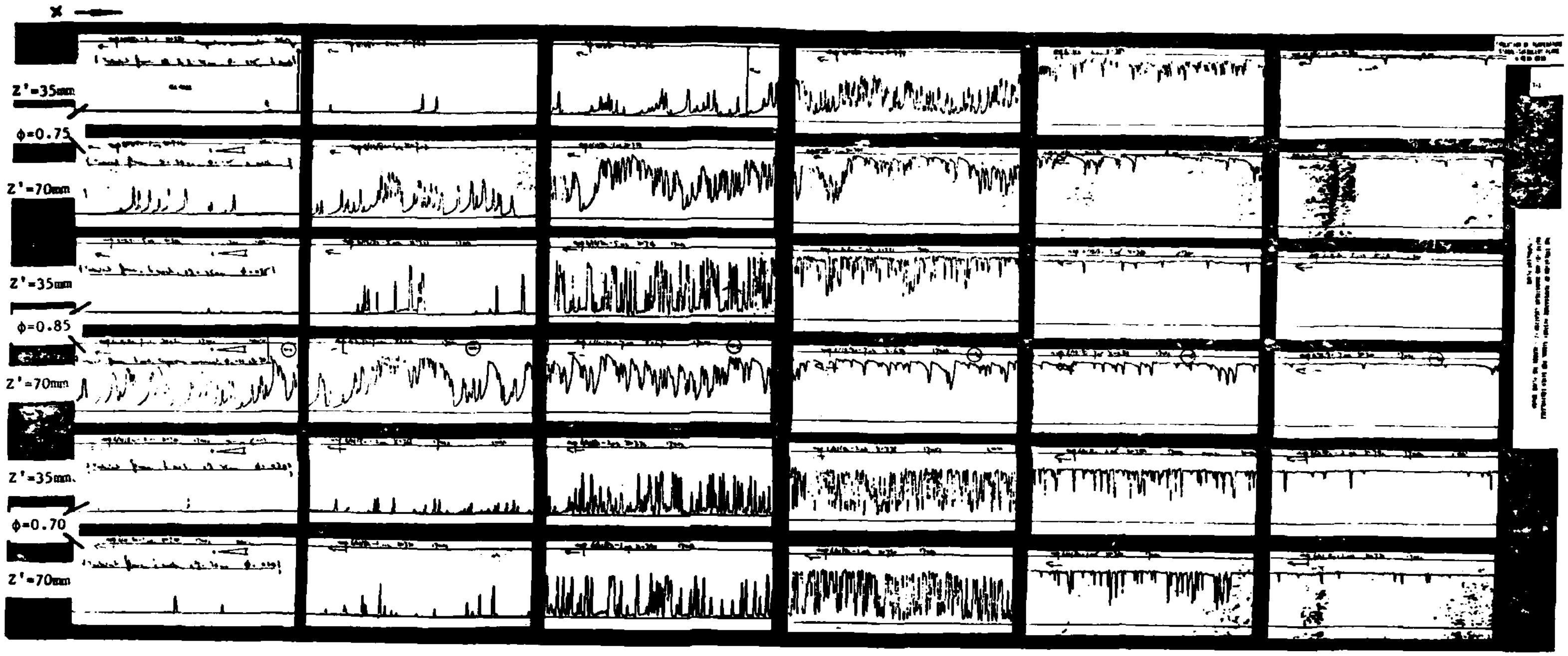


THE EVOLUTION OF TEMPERATURE HISTORY SIGNAL FOR GIVEN EQUIVALENCE RATIO (ϕ) AND DOWNSTREAM LOCATION (Z') ACROSS THE FLAME BRUSH - LAMINAR FLAME; ALL PASS SIGNAL



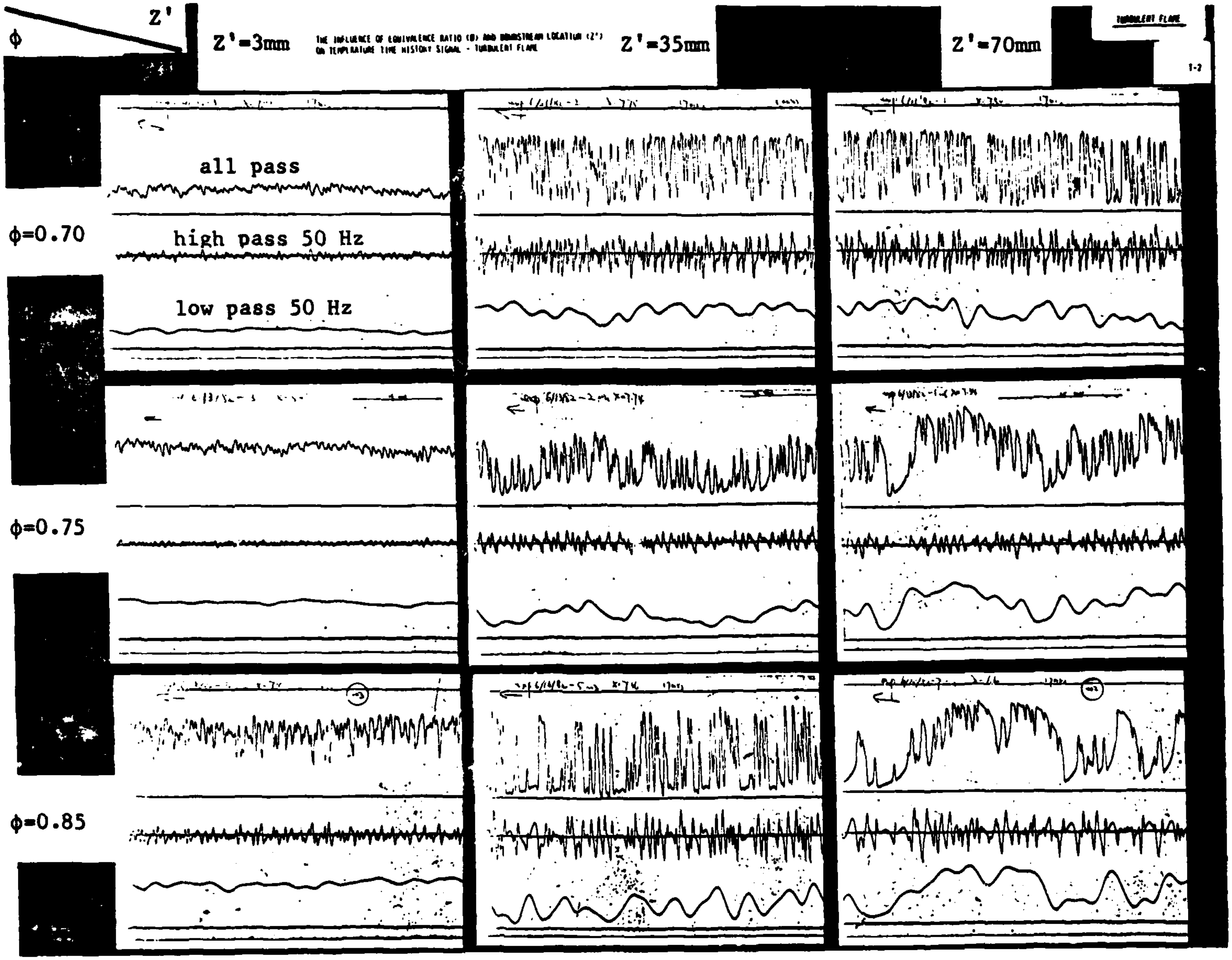
THE INFLUENCE OF EQUIVALENCE RATIO (ϕ) AND DOWNSTREAM LOCATION (Z') ON TEMPERATURE TIME HISTORY SIGNAL - LAMINAR FLAME; MAX. TEMP. FLUCTUATIONS

Fig. 3



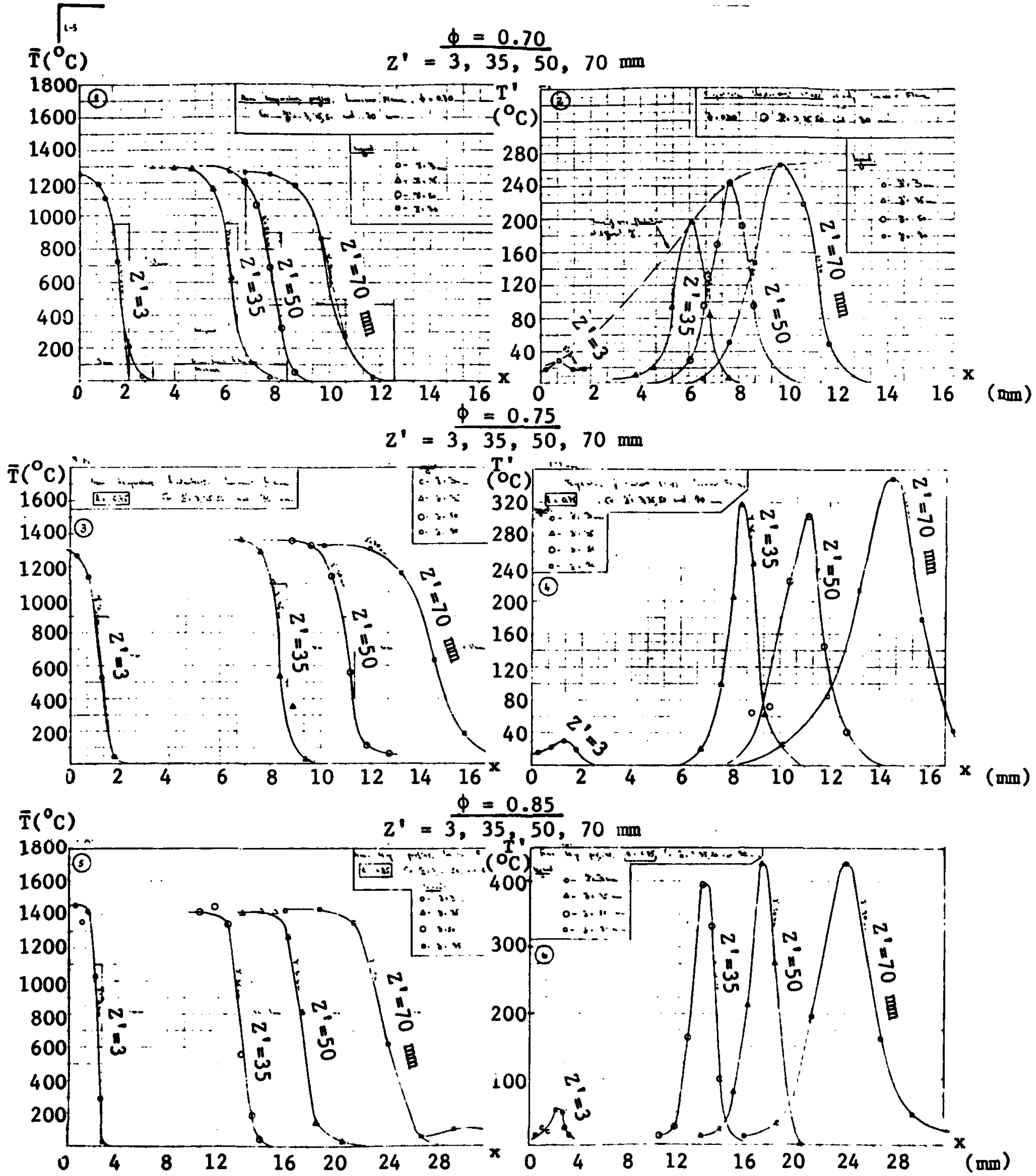
THE EVOLUTION OF TEMPERATURE HISTORY SIGNAL FOR GIVEN EQUIVALENCE RATIO (φ) AND DOWNSTREAM LOCATION (Z') ACROSS THE FLAME BRUSH - TURBULENT FLAME; 4 MESH GRID

Fig 4



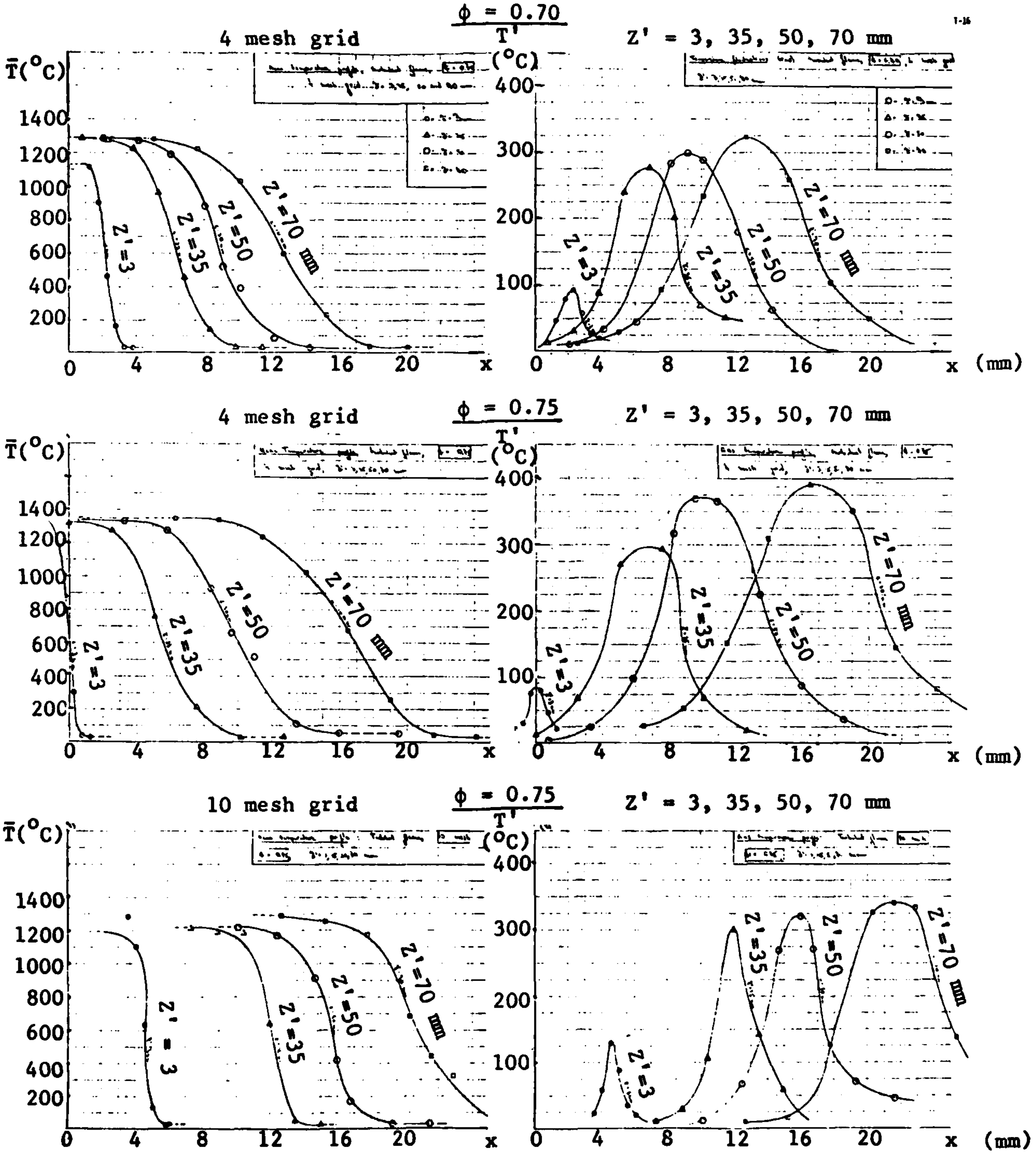
THE INFLUENCE OF EQUIVALENCE RATIO (ϕ) AND DOWNSTREAM LOCATION (Z') ON TEMPERATURE TIME HISTORY SIGNAL - TURBULENT FLAME: 4 MESH GRID

Fig. 5



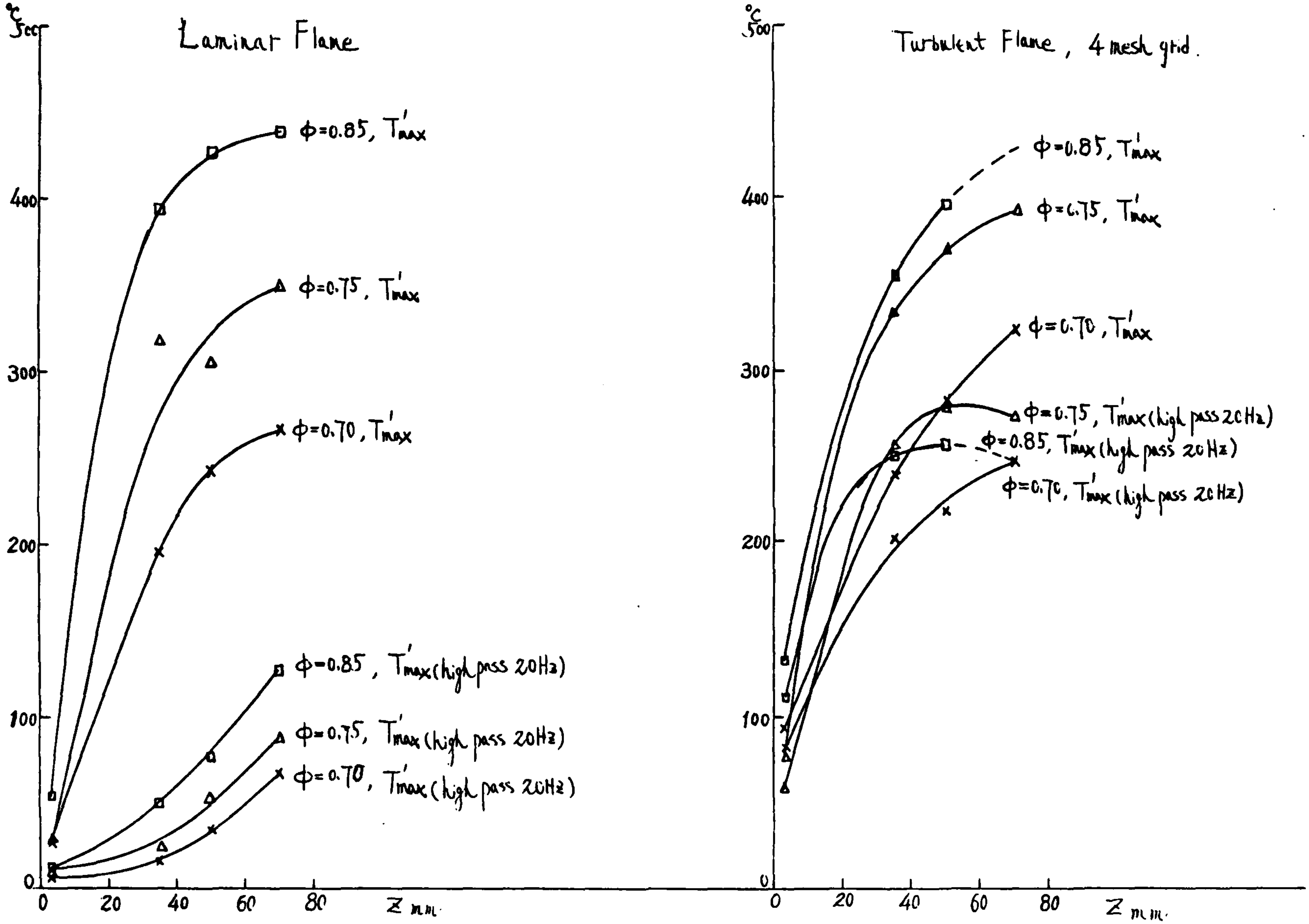
MEAN AND RMS TEMPERATURE PROFILES - LAMINAR FLAME

Fig. 6



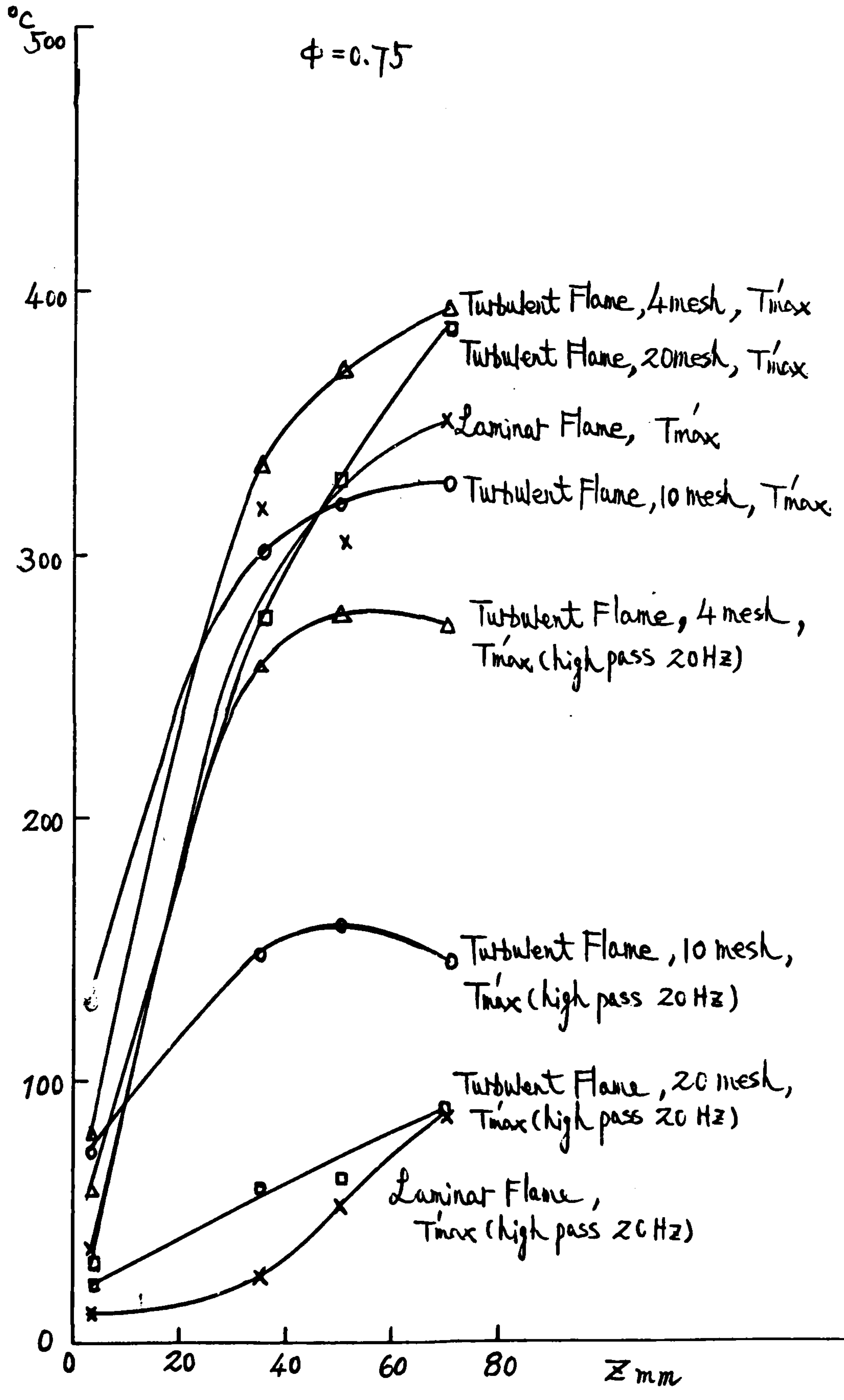
MEAN AND RMS TEMPERATURE PROFILES ACROSS THE FLAME BRUSH - TURBULENT FLAME; 4 MESH GRID AND 10 MESH GRID

Fig. 7



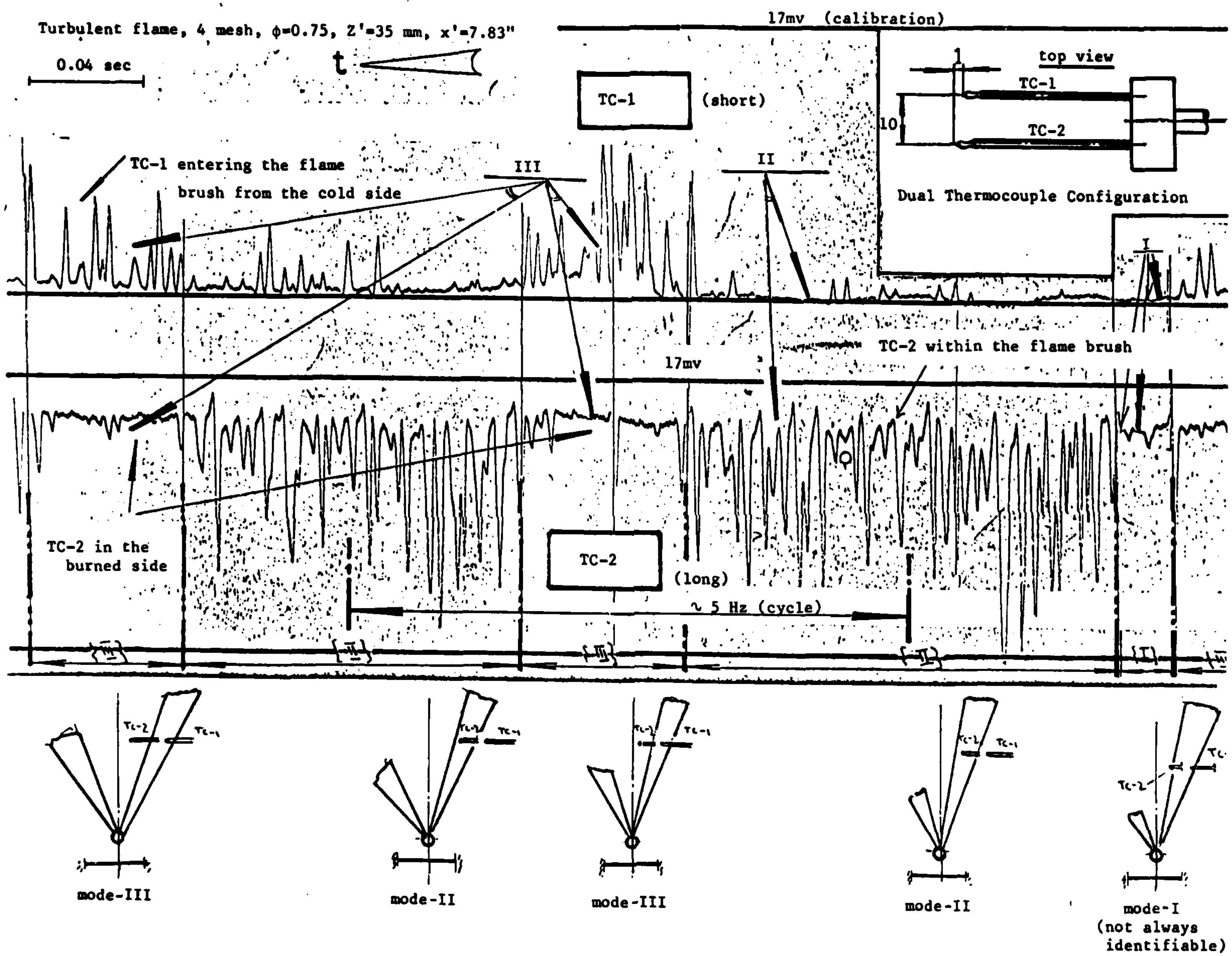
EFFECTS OF EQUIVALENCE RATIO ON MAXIMUM RMS TEMPERATURE FLUCTUATIONS (ALL-PASS AND HIGH-PASS) AT DIFFERENT DISTANCES FROM THE FLAMEHOLDER FOR LAMINAR AND TURBULENT FLAMES

Fig. 8



DEVELOPMENT OF MAXIMUM RMS TEMPERATURE FLUCTUATIONS (ALL-PASS AND HIGH-PASS) FOR LAMINAR AND TURBULENT FLAMES WITH DIFFERENT MESH SIZES OF TURBULENCE-GENERATING GRIDS

Fig. 9



Turbulent flame, 4 mesh, φ=0.75, Z'=35 mm, x'=7.83"
0.04 sec
t
17mv (calibration)
TC-1
(short)
top view
TC-1
TC-2
10
1
Dual Thermocouple Configuration
TC-1 entering the flame brush from the cold side
III
II
I
17mv
TC-2 within the flame brush
TC-2 in the burned side
TC-2
(long)
~ 5 Hz (cycle)
mode-III
mode-II
mode-III
mode-II
mode-I (not always identifiable)

Fig. 10

PREIGNITION OXIDATION CHARACTERISTICS OF HYDROCARBON FUELS

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Program Summary

Ignition is a complex process involving preignition reactions which lead up to the point of hot ignition. It is the preignition behavior of the system which determines whether or not ignition occurs. An understanding of the global preignition oxidation mechanisms, the associated heat release rates, and the controlling fuel and physical factors will become essential when synthetic and poorer quality petroleum fuels come into wider use.

Consequently, in April 1980, a study of the preignition behavior of hydrocarbon fuels was initiated under the sponsorship of the Army Research Office (ARO Numbers: DRXRO-EG-16957; DAAG 29-80-C-0112). The specific objectives for the study are:

(1) to determine the quantitative and qualitative factors important to ignition delay for a variety of fuels; and

(2) to determine the global oxidation mechanisms and heat release rates for these fuels during the preignition reaction process.

The experimental program utilizes gas chromatographic profiling and analysis techniques to qualitatively and quantitatively assess the reactants, products, and stable reaction intermediates during the preignition oxidation process. These species are being followed in time up to the point of hot ignition in a static reactor test facility exercised over a range of operating conditions. Analysis and interpretation of these data will lead to attainment of the above objectives.

Work to date has focused on developing and verifying the experimental and analytical systems and on carrying out exploratory and preliminary measurements in the system. Reproducibility of the system has been established and anticipated effects of temperature and pressure have been confirmed. The ability to follow the distribution of products and stable intermediates over the course of reaction has been demonstrated. Currently, additional verification work is underway and detailed testing of pure fuels and pure fuel blends, with and without additives, will commence shortly.

PREIGNITION OXIDATION CHARACTERISTICS OF HYDROCARBON FUELS

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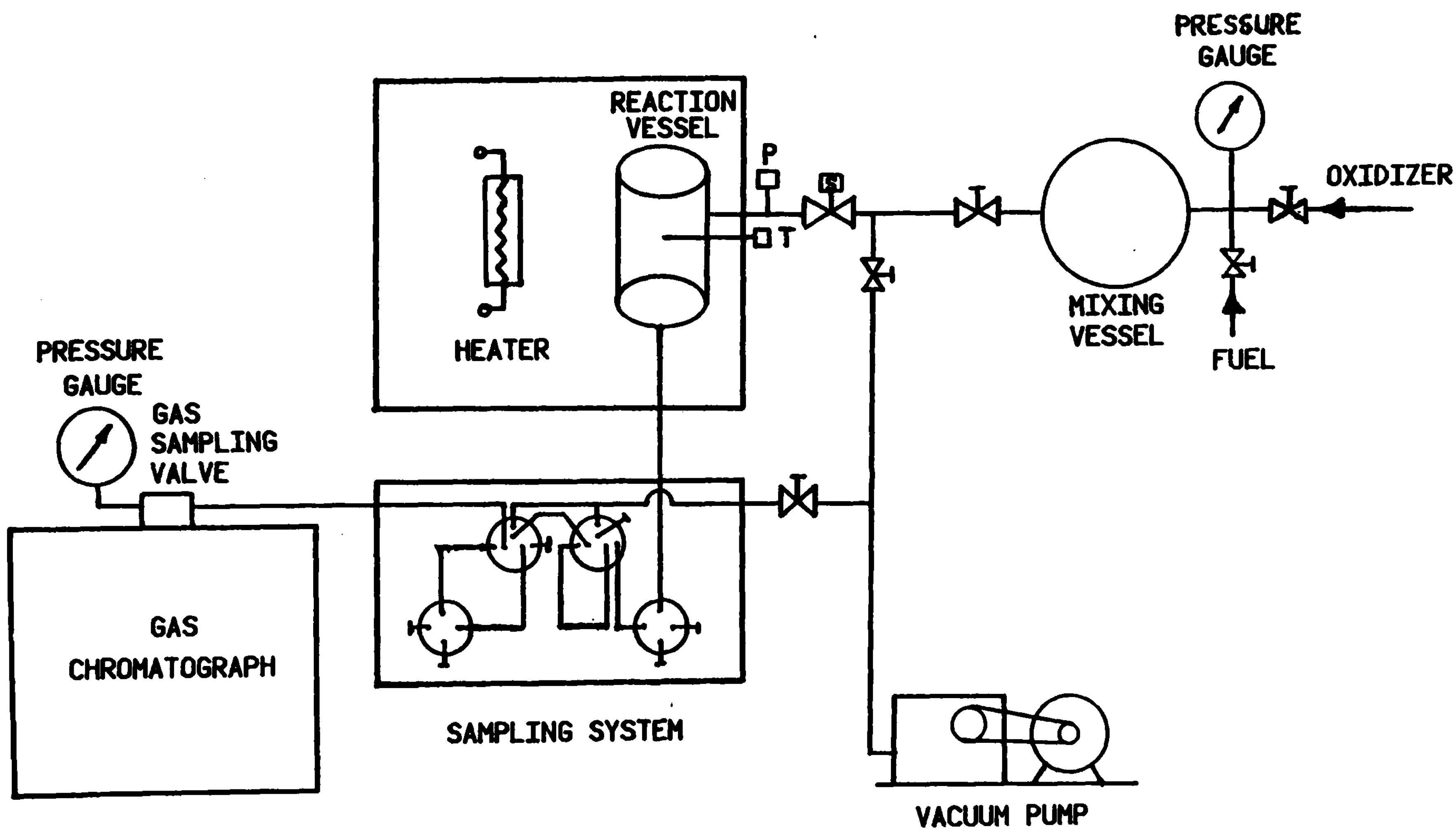
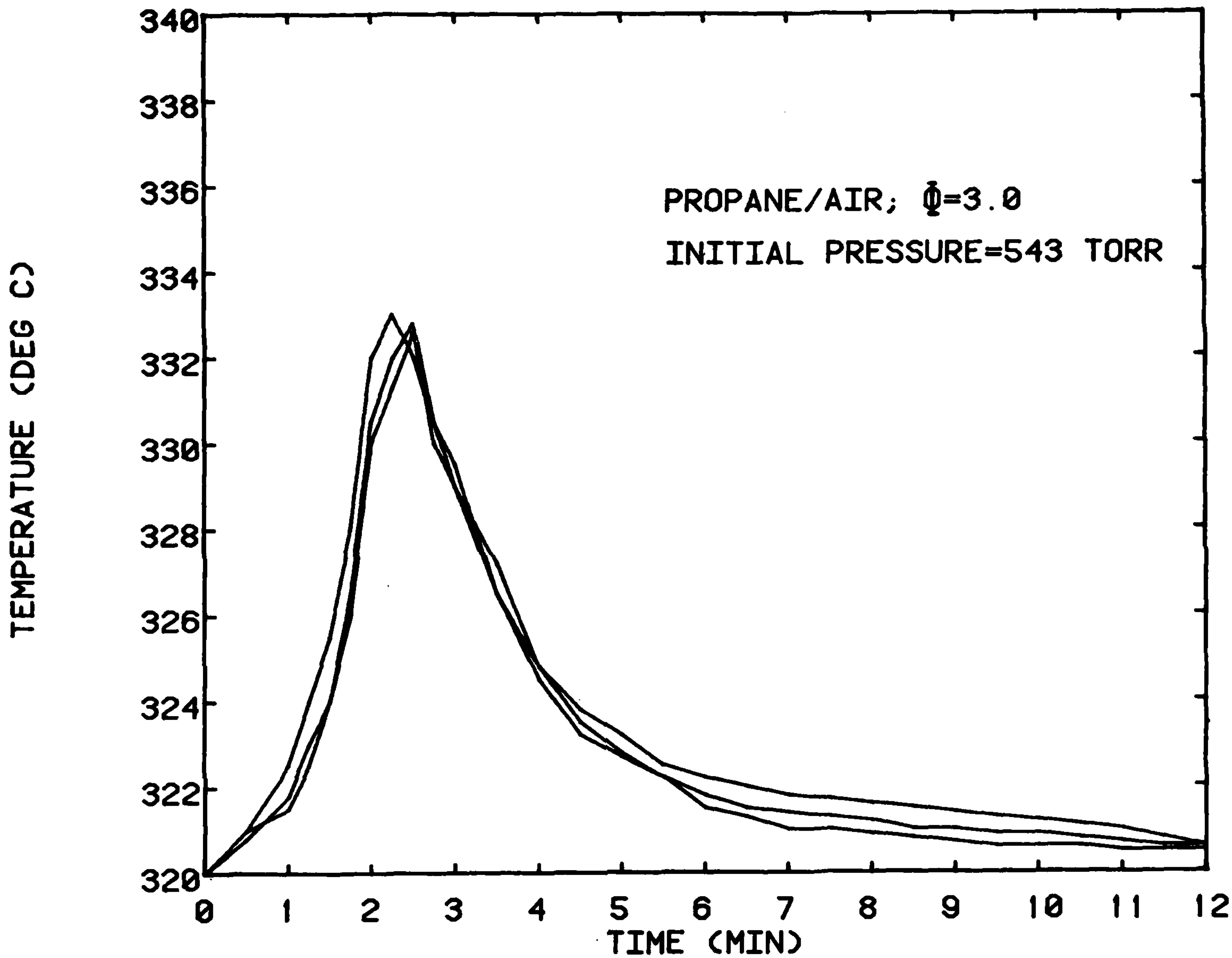
PROGRAM TO STUDY THE PREIGNITION OXIDATION CHARACTERISTICS OF HYDROCARBON FUELS

OBJECTIVES

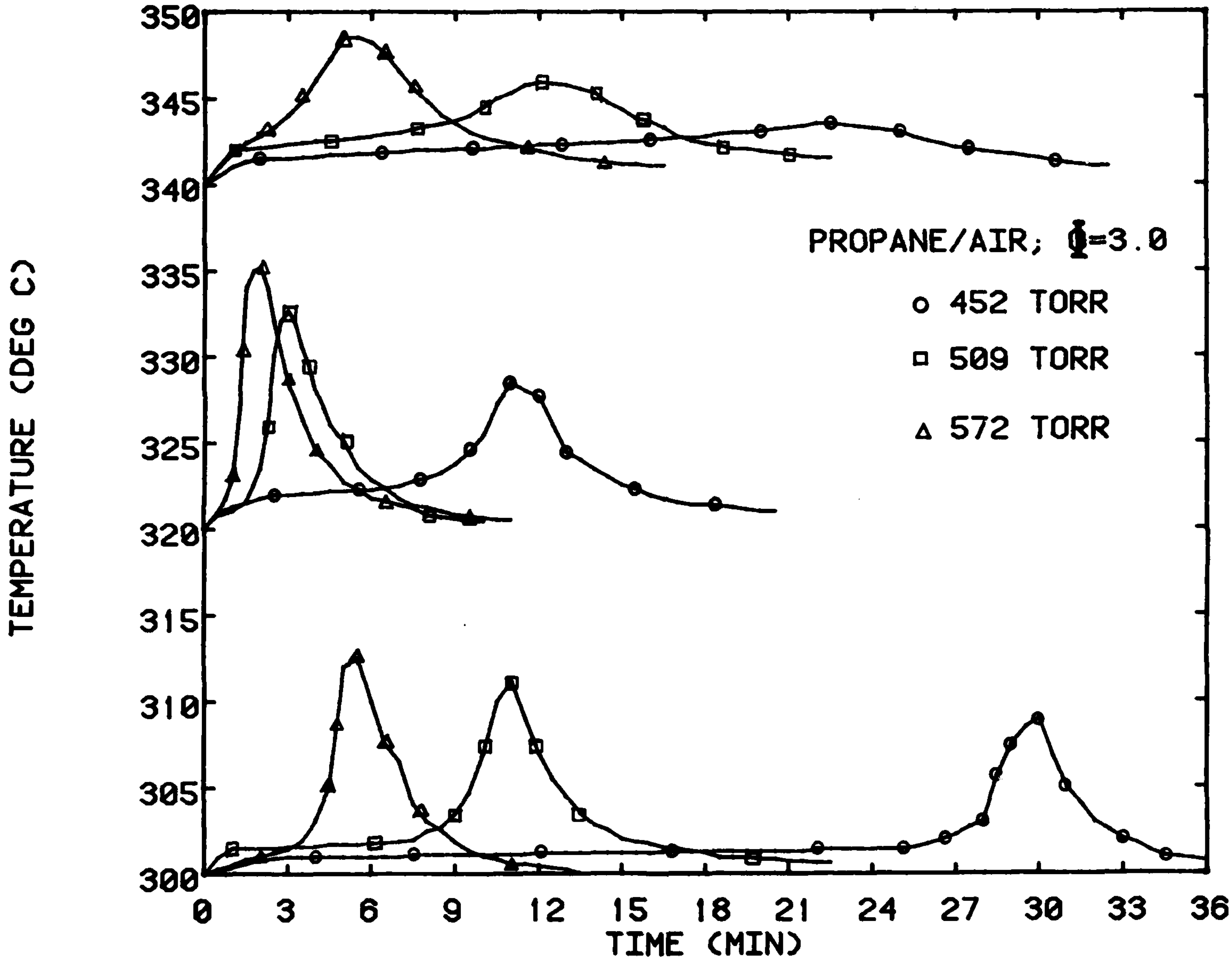
- TO EXTEND AND COMPLIMENT PREVIOUS WORK
  - DEVELOP SPECIES INFORMATION DURING PREIGNITION PROCESSES
  - INCLUDE HIGHER CARBON NUMBER FUELS
  - EXAMINE THE EFFECTS OF FUEL MIXTURES AND ADDITIVES
- TO DETERMINE GLOBAL OXIDATION MECHANISMS AND HEAT RELEASE RATES



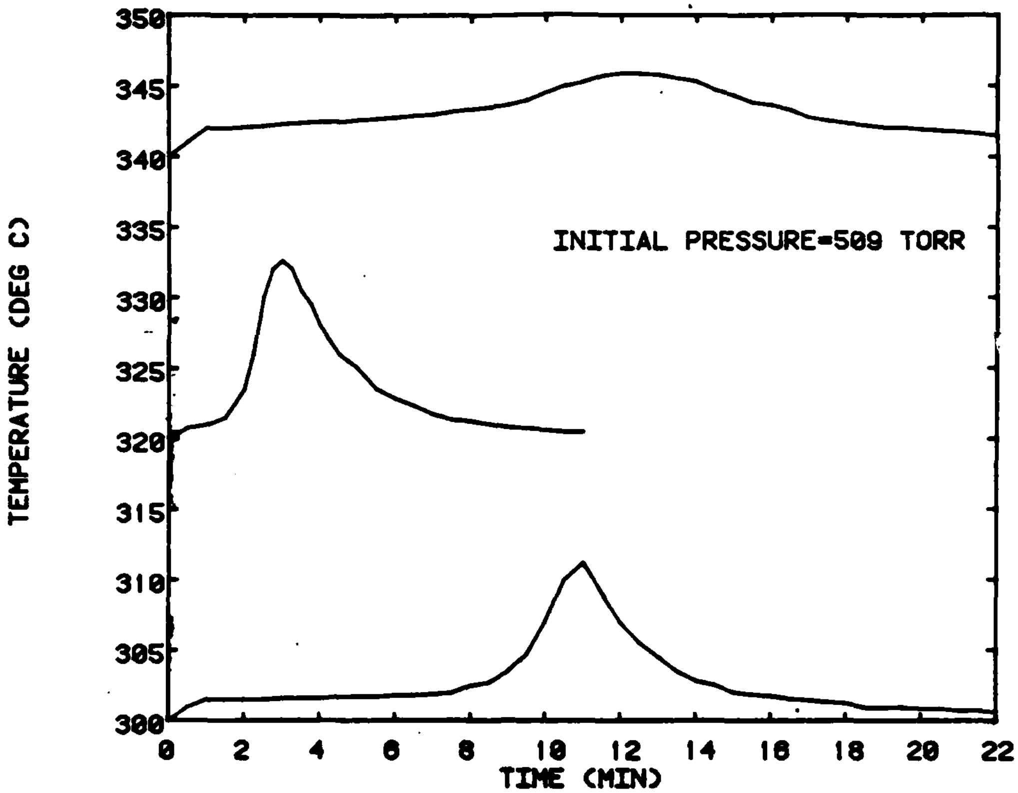
EXPERIMENTAL FACILITY

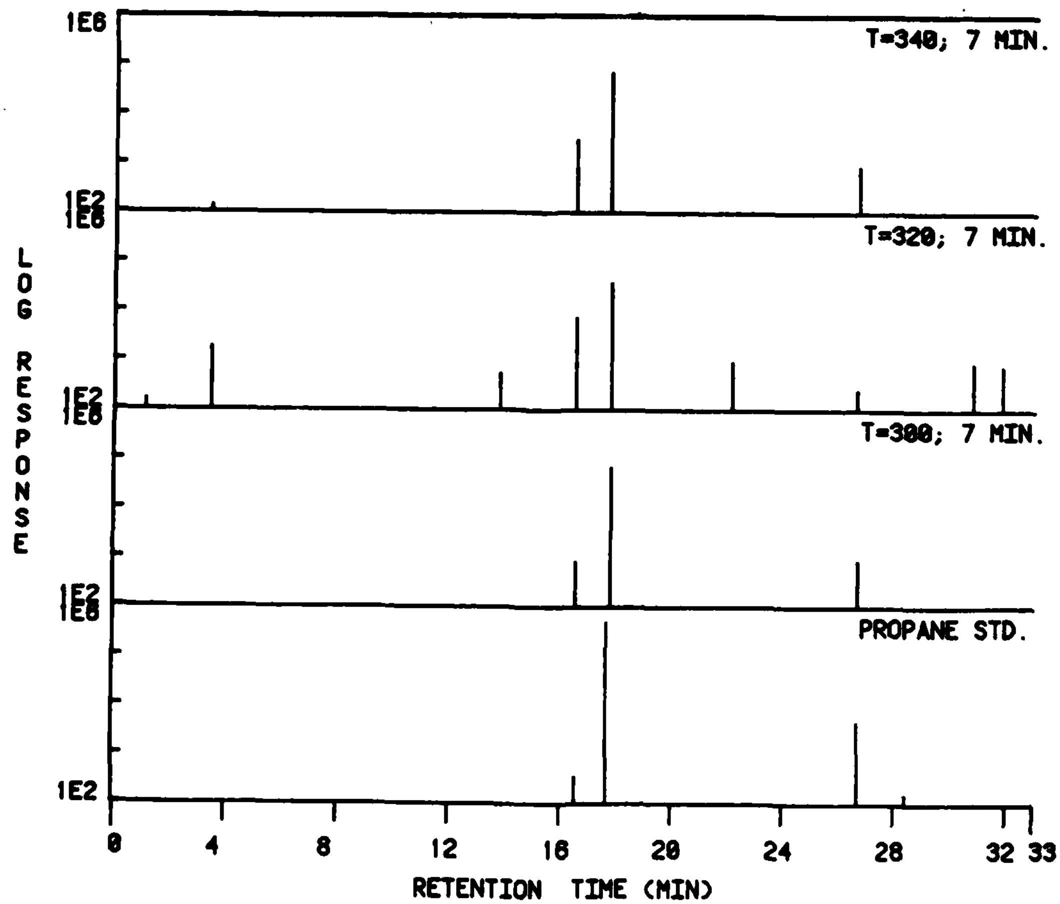


REPRODUCIBILITY OF TEMPERATURE PROFILES

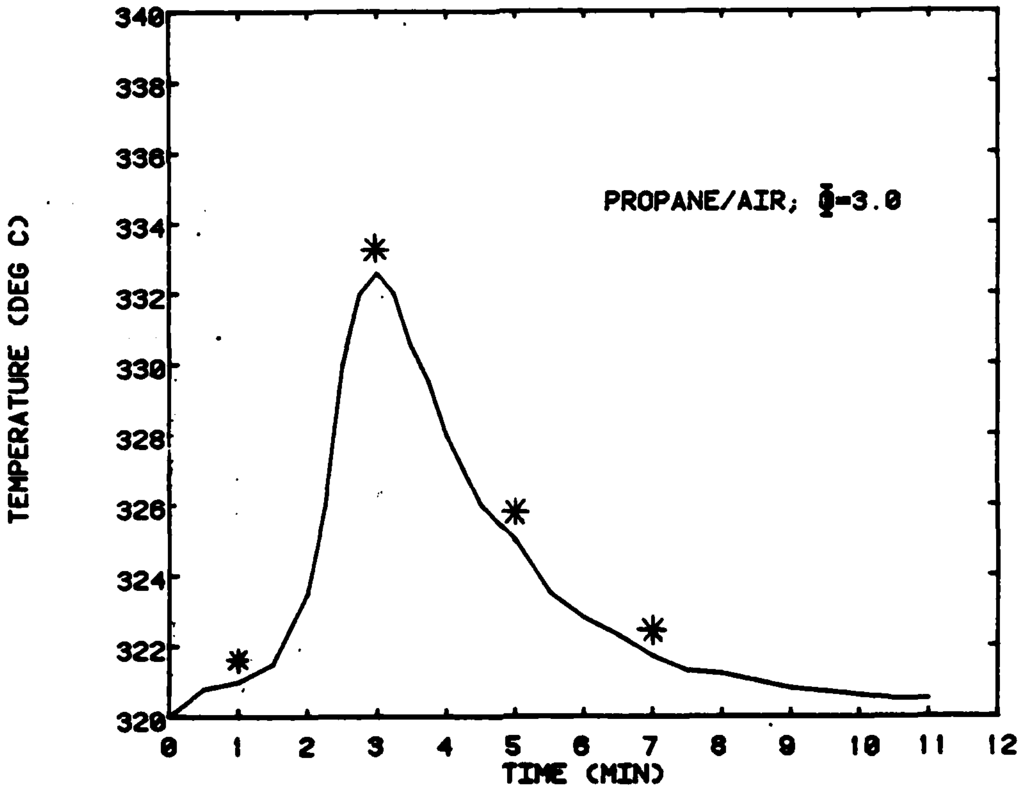


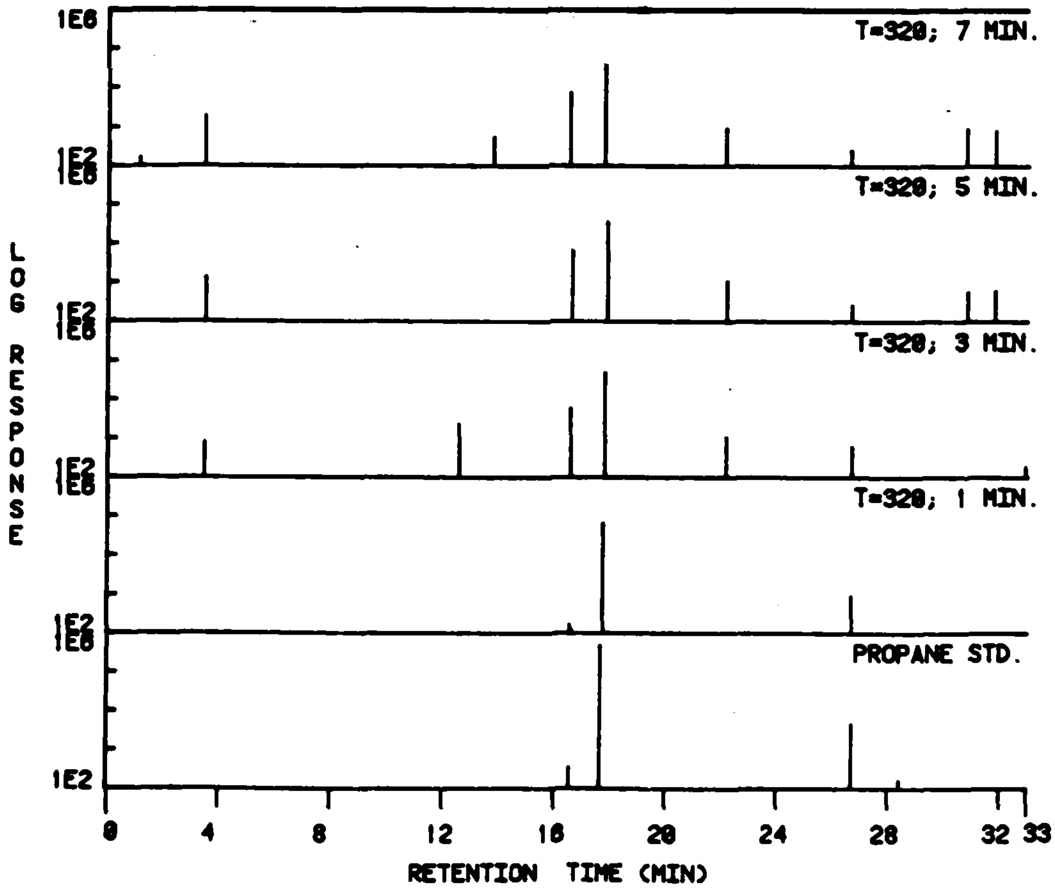
PRESSURE EFFECT ON TEMPERATURE PROFILES





TEMPERATURE EFFECT ON PEAK PROFILES





EFFECT OF SAMPLING TIME ON PEAK PROFILES

SUMMARY AND CONCLUSIONS

- A STATIC REACTOR FACILITY AND A CHROMATOGRAPHIC PEAK PROFILING SYSTEM HAVE BEEN DEVELOPED FOR STUDYING THE PREIGNITION OXIDATION BEHAVIOR OF HYDROCARBONS

- PRELIMINARY TESTING HAS BEEN CARRIED OUT

  - SYSTEM OPERATES REPRODUCIBLY

  - TEMPERATURE PROFILES ARE CONSISTENT WITH THE EXPECTED BEHAVIOR IN THE COOL FLAME REGION

  - INCREASING INITIAL PRESSURE AND TEMPERATURE PRODUCES THE EXPECTED SHORTENING OF THE INDUCTION PERIOD

  - THE DISTRIBUTION AND NUMBER OF STABLE REACTION INTERMEDIATES AND PRODUCTS ARE AFFECTED BY OPERATING CONDITIONS AND CAN BE FOLLOWED DURING THE COURSE OF REACTION

CURRENT AND FUTURE WORK

- QUANTIFICATION OF SURFACE EFFECTS
- MODIFICATIONS TO PERMIT THE USE OF LIQUID FUELS
- DETAILED TESTING OF PURE FUELS AND PURE FUEL BLENDS, WITH AND WITHOUT ADDITIVES
- IDENTIFICATION OF IMPORTANT SPECIES AND DETERMINATION OF MECHANISMS

Session 3
ARO DIESEL ENGINE RESEARCH

Chairman: P. C. Glance
U. S. Army Tank-Automotive Command
Warren, MI

DIESEL SPRAYS

Norman Chigier

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The main objective of this research is to establish the basic mechanisms of atomization and vaporization in pulsed diesel sprays. Characterization of diesel sprays requires measurement of particle size distribution and particle velocity as a function of space and time. High speed cinematography provides visualization of global features of the spray as it penetrates into the air flow field. Laser induced fluorescence will allow study of motion of sections of the spray and of individual drops. A major problem is to differentiate between the presence of drops in a dense spray and the presence of bulk liquid, ligaments and large agglomerations of drops. Because of the high density of the sprays, laser light obscuration can be of the order of 90%, causing great difficulty in using pulsed laser imaging techniques and laser interferometric methods for particle sizing and velocity measurement.

The Malvern instrument yields measurements at laser light obscuration as high as 90% but calibration and interpretation of the measurements is required due to multiple scattering and interference effects. X-rays and ultraviolet radiation would allow greater penetration through the dense sprays; the feasibility of extending flash imaging techniques to these regions of the energy spectrum needs exploring.

The diode arrays in the Malvern instrument are multiplexed as the intensity is measured in each diode sequentially. This sequence of events is too long for measurements to be made in diesel sprays with lifetimes of the order of 10 ms. By simultaneous recording of time histories from each diode, for several pulses of the spray, the light intensity distribution can be reconstructed to yield drop size distributions as a function of time, after start of injection, at a particular location in the spray. Initial attempts at making such measurements have demonstrated the feasibility of using the

Diesel Sprays
N. Chigier

Malvern for drop size measurement in diesel sprays but further development is required to improve accuracy.

Trajectories of individual drops determine the location of deposition of fuel vapor and hence the distributions of local fuel vapor/air ratios. Since soot formation is promoted in fuel rich regions with high temperature gradients, knowledge of profiles of temperature and gas concentration enable the identification of soot forming regions within the spray flame. Since soot burning is promoted in regions of lean mixture ratio with high temperature and residence time, knowledge of temperature and gas concentration profiles also enable identification of soot burning regions within the spray flame.

A high pressure, high temperature chamber has been designed to study diesel sprays injected into air environments simulating conditions in the engine cylinder prior to ignition. An electromagnetically controlled injector has been acquired from GM for controlled injection of fuel into the chamber. A Malvern particle sizing instrument has been purchased and is undergoing calibration. A High-cam, high speed motion camera is available for visualization studies.

OBJECTIVES

FUNDAMENTAL STUDY OF ATOMIZATION OF PULSED DIESEL SPRAYS

CHARACTERIZATION OF DIESEL SPRAYS BY DETERMINATION OF DROP SIZE AND VELOCITY DISTRIBUTIONS

ESTABLISHMENT OF TRAJECTORIES OF INDIVIDUAL DROPLETS OF VARYING SIZE AND MOMENTUM WITHIN SPRAY

MEASUREMENT OF RATE OF VAPORIZATION OF DROPLETS AS A FUNCTION OF AMBIENT TEMPERATURE, PRESSURE, AND FUEL VAPOR CONCENTRATION

DETERMINATION OF LOCAL FUEL-AIR MIXING RATIOS AND THE EFFECT ON SOOT FORMATION

FUNDAMENTAL QUESTIONS

WHAT IS THE LIFETIME OF LIQUID FUEL DROPLETS IN DIESEL ENGINE CYLINDERS.

HOW DOES ATOMIZATION INFLUENCE SPRAY CHARACTERISTICS AND VAPORIZATION.

TO WHAT EXTENT DO LIQUID PARTICLES IMPINGE ON SOLID SURFACES.

HOW DO VARIATIONS IN LOCAL VAPOR FUEL/AIR RATIOS AFFECT SOOT FORMATION AND OXIDATION.

INSTRUMENTATION

HIGH SPEED SCHLIEREN MOTION PICTURE

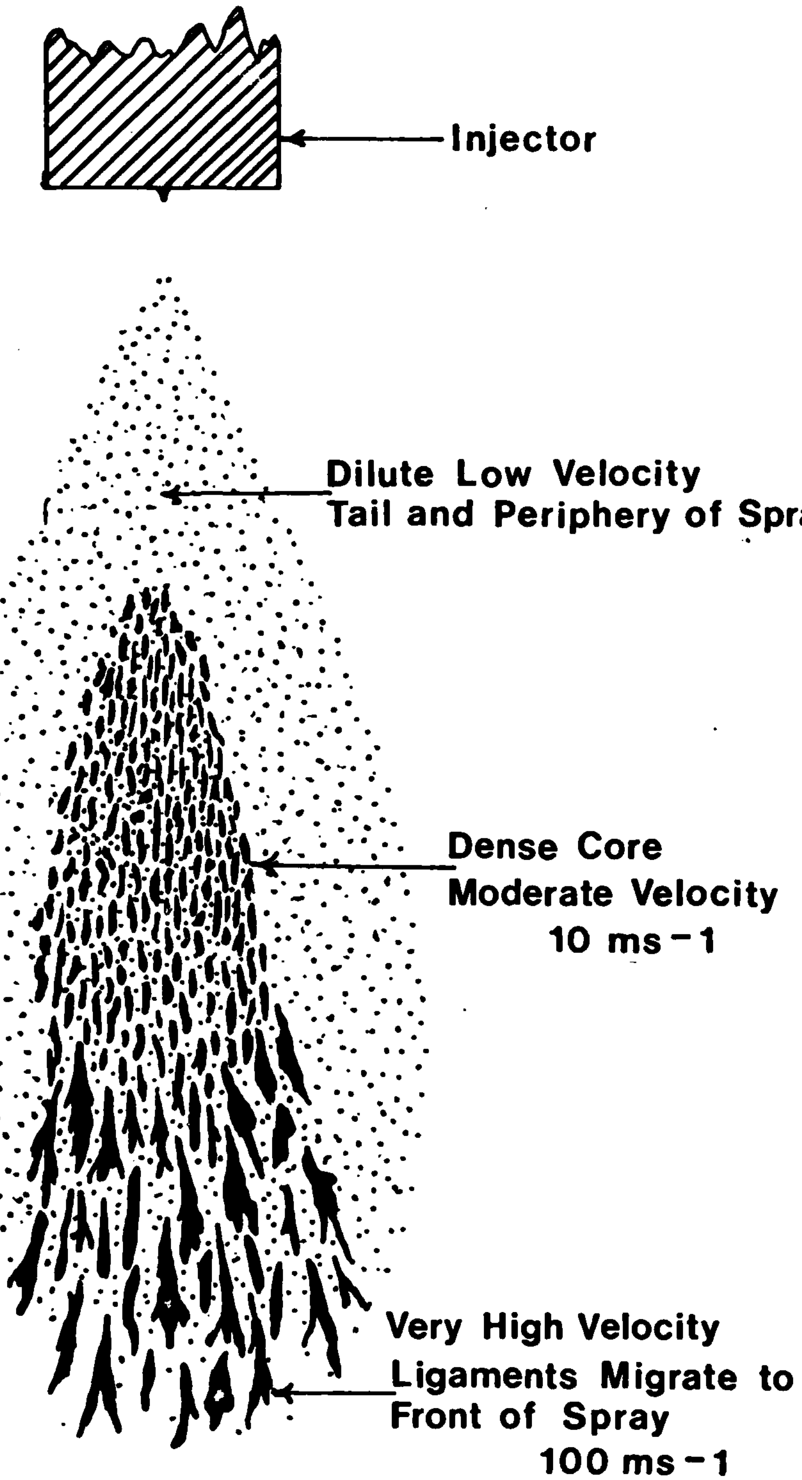
PULSED LASER PHOTOGRAPHY AND HOLOGRAPHY

LASER DOPPLER ANEMOMETER AND INTERFEROMETER

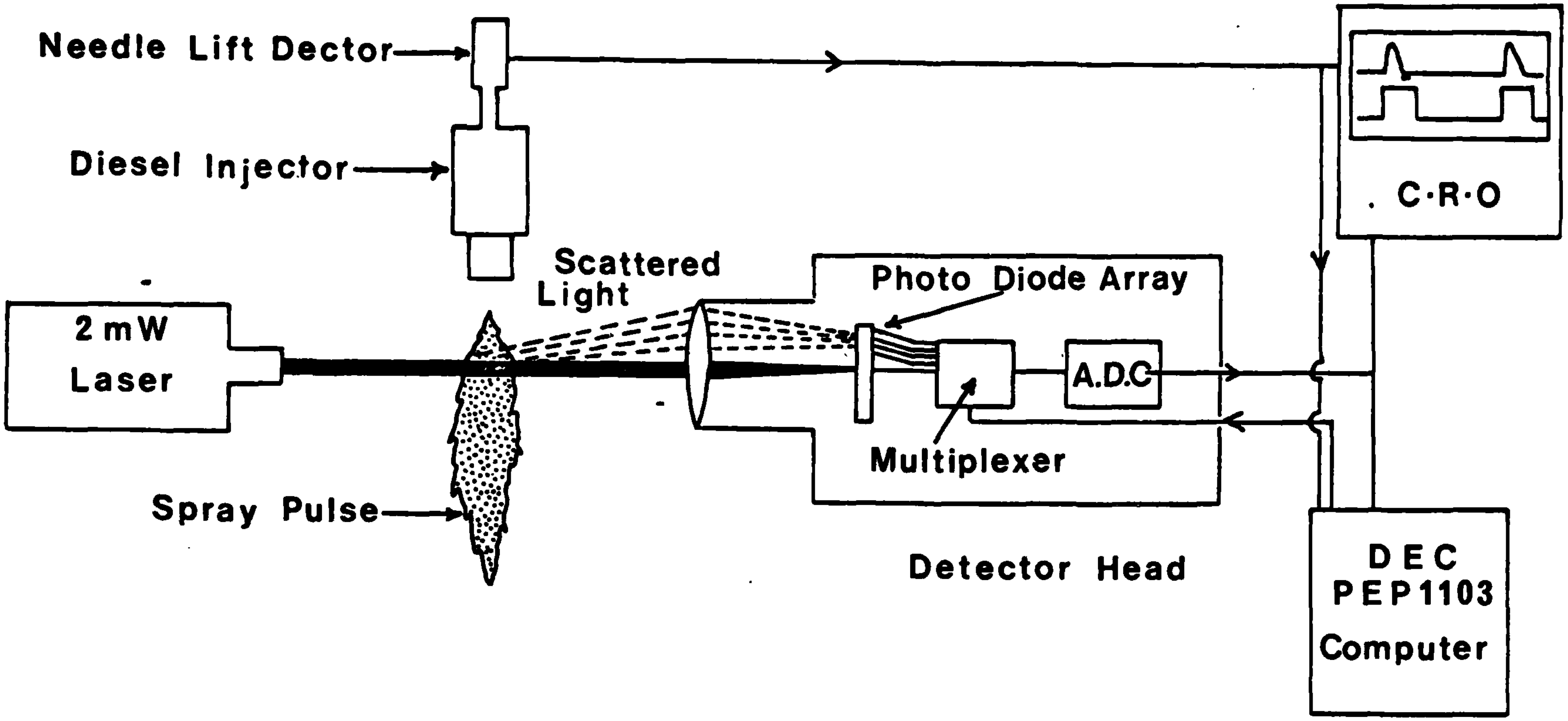
LASER DIFFRACTION PARTICLE SIZER

X-RAY FLASH RADIOGRAPHY

MICROTHERMOCOUPLES



SCHEMATIC DIAGRAM OF ZONES OF TYPICAL SPRAY PULSE



INSTRUMENTATION FOR PARTICLE SIZE MEASUREMENT IN DIESEL SPRAYS USING LIGHT SCATTERING

ARO/MERADCOM Engines/Fuels Workshop
Southwest Research Institute
San Antonio, Texas, Dec. 7-8, 1982

Atomization and Thick Sprays

DAAG 29-81-K-0135

F.V. Bracco
Princeton University

ABSTRACT

Sprays are considered from single cylindrical orifices under the conditions of direct fuel injection in internal combustion engines.

The main conclusions of earlier measurements pertaining to the jet break up process are summarized first (p.2). From them it is possible to compute the spreading angle of the spray at the nozzle exit and the average size of the drops formed by the break-up of the outer surface of the jet near the nozzle exit.

Measurements are then reported of the axial component of the drop velocity 2 to 12 cm from the nozzle. The measurements were made by LDV under various conditions and at several radial and axial locations (pp.3-5).

Starting from the initial angle and drop size at the nozzle exit, the downstream drop velocities were then computed with an advanced spray model and compared with the measured ones (pp.6-8).

A brief summary follows of our current understanding of the structure of these sprays (p.9).

Finally, this and related studies led us to some questions about engine flows and combustion that are put forth as our contribution to the general discussion (p.10).

$$\tan\frac{\theta}{2} \approx \frac{1}{A}\,(\rho_g/\rho_\ell)^{1/2} \tag{1}$$

$$\bar{x} \approx C\,\sigma_\ell/\rho_g\,V_{inj}^2 \tag{2}$$

JET BREAKUP

The break up of the outer surface of the jet occurs on the time scale of microseconds and therefore is quasi steady with respect to the changing engine conditions [1]. This breakup starts in the immediate vicinity of the orifice exit. Aerodynamic interaction between the liquid surface and the gas induces rapid and selective growth of perturbations that originate within the nozzle [2]. The initial angle of the spray is thus set and found to depend most strongly on the nozzle design and the gas-to-liquid density ratio as shown in Eq. (1) in which A is a constant for a given nozzle design [3]. The initial size of the drops formed by the breakup of the outer surface of the jet is determined by the Weber number and is insensitive to the nozzle geoemtry as shown in Eq. (2) in which $\bar{x}$ is the volume-mean drop diameter and C $\approx$ 10 [4].

The mechanism by which the nozzle geometry influences the breakup of the outer surface of the jet and the mode of break up of the inner core of the jet are not known at present.

P_g (MPa)	ρ_g/ρ_ℓ	Δp (MPa)	V_{inj} (m/s)	Nozzle d(μm)	L/D	X/D
1.48	0.0256	11.0	127	127	4.0	300,400,600,800
4.24	0.0732	11.0	127	127	4.0	300,600
4.24	0.0732	26.2	194	127	4.0	400,500
1.48	0.0256	11.0	125	76.2	1.0	300,500
4.24	0.0732	11.0	125	76.2	1.0	300

Liquid: n-hexane ρ_ℓ = 665 kg/m^3

Gas: nitrogen μ_ℓ = $3.2\text{x}10^{-4}$ N•s/m^2

σ_ℓ = 1.84×10^{-2} N/m

Table 1

DROP VELOCITY MEASUREMENTS

Using an LDV system, radial distributions of the axial drop velocities were measured at several axial locations within steady, isothermal sprays, including regions with very high drop number densities ($> 10^{11}$ m^{-3}) and velocity gradients (up to 5 m/s per mm). The LDV system consisted of: an argon ion laser at 514.5 nm; dual beam, 90° scatter mode; 0.2x0.2x0.7 mm^3 probe volume; 6.17 μm fringe spacing; no frequency shift; counter signal processor. The minimum distance from the nozzle was 300 nozzle diameters (2.3 cm). n-hexane was injected into compressed nitrogen at two injection velocities (127 and 194 m/s) and through two single-hole round nozzles of different diameter (127 and 76.2 μm) and length-to-diameter ratio (4 and 1). Two ratios of the gas density to the liquid density were used (0.0256 and 0.0732). The test conditions are summarized in Table 1.

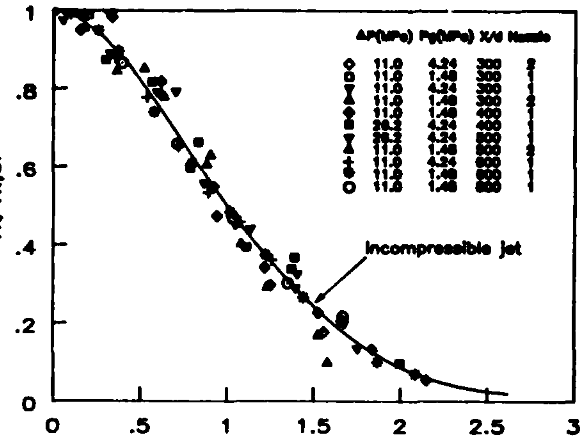


FIG. 1 $r/r_{.5}$

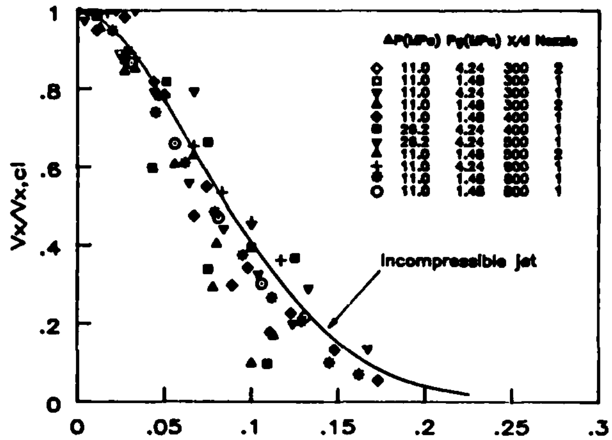


FIG. 2 r/X

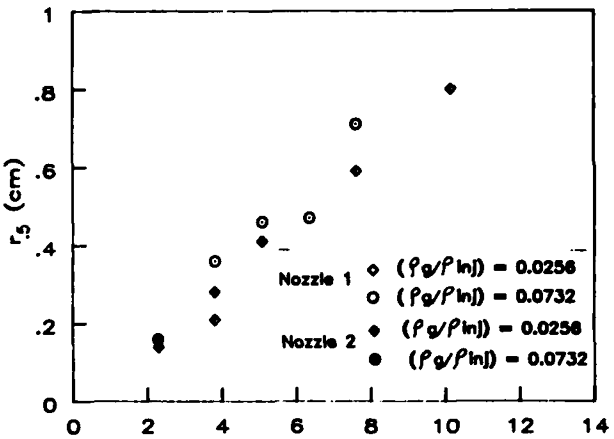


FIG. 3 X (cm)

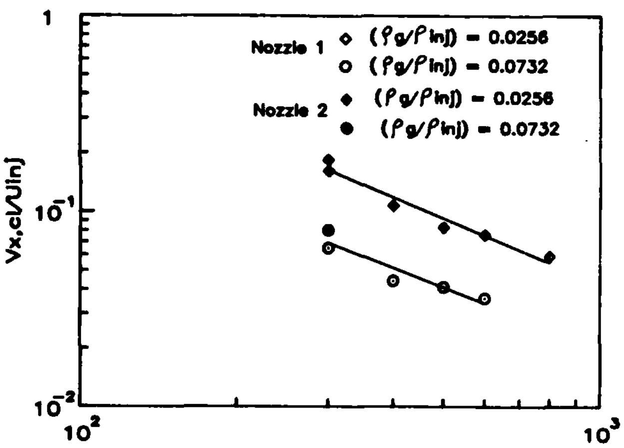


FIG. 4 X/d

The measured radial distributions of the mean and fluctuating components of the drop velocity were found to be very similar in trends and magnitudes to the corresponding distributions of the fluid velocity in the far field of incompressible jets (Figs. 1,6-8). Thus the drop velocity field tends to the universal fluid velocity field of incompressible jets. However, whereas incompressible jets achieve their self preserving configuration, some 50 diameters from the injector [5], the drop velocities achieve a similar configuration more than 300 diameters from the injector in these dense, non-vaporizing sprays (Figs. 2,3).

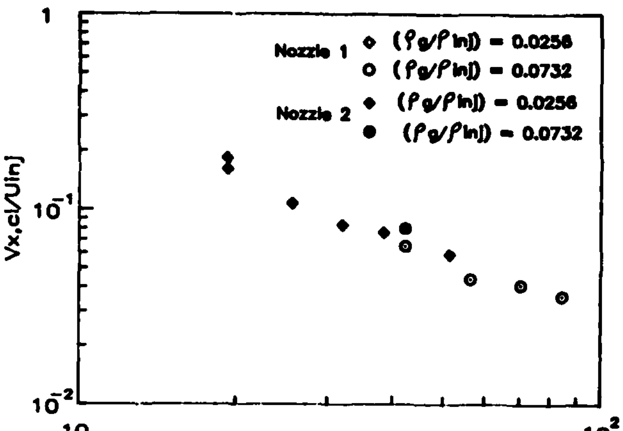


FIG. 5

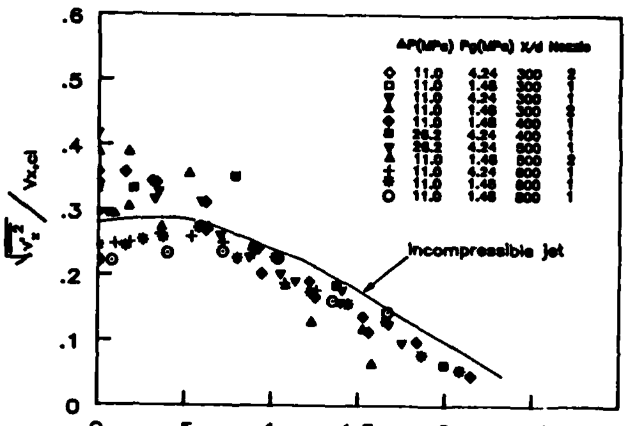


FIG. 6

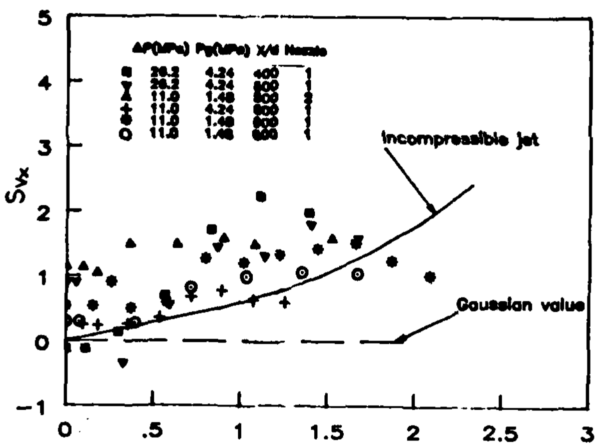


FIG. 7

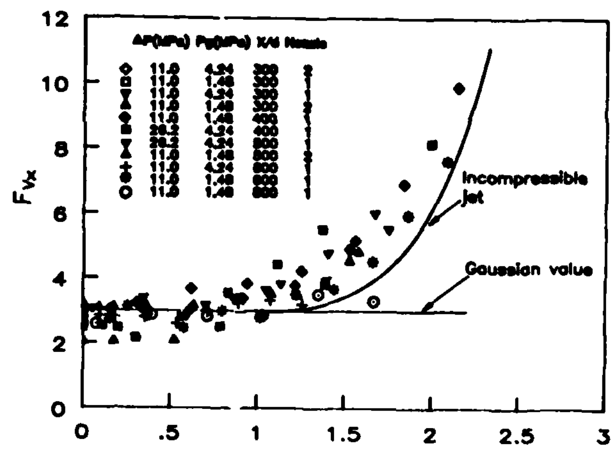
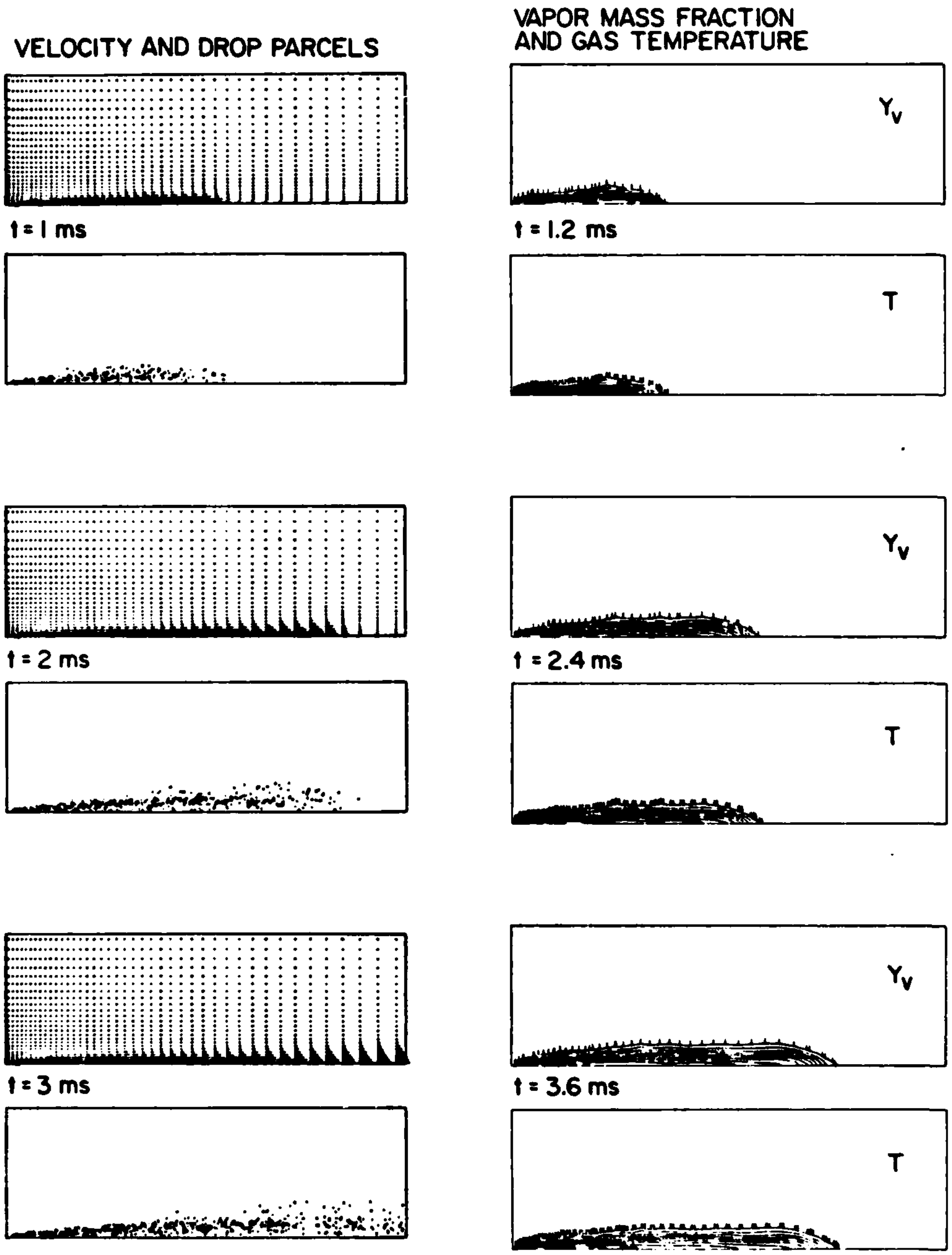


FIG. 8

The greater is the density of the injected fluid with respect to that of the environment, the slower the decay of the jet velocity and the faster the penetration (Fig. 4). It is as if the axial scale of the jet is stretched proportionally to $(\rho_\ell/\rho_g)^n$ where n tends to 1/2 in the far field [6], to 1 near the injector [7] and may be close to 3/4 in the range of our measurements (Fig. 5). Details of these measurements are in [10].



a) FIG. 9 b)

DROP VELOCITY COMPUTATIONS

Having the initial angle and drop size, computations can be made of the subsequent development of the spray and the computed downstream results compared with the corresponding downstream measurements. The initial drop size is randomly selected from a distribution with mean value given by Eq. 2, and the initial angle of the drop velocity is randomly selected from a distribution between zero and that given by Eq. 1.

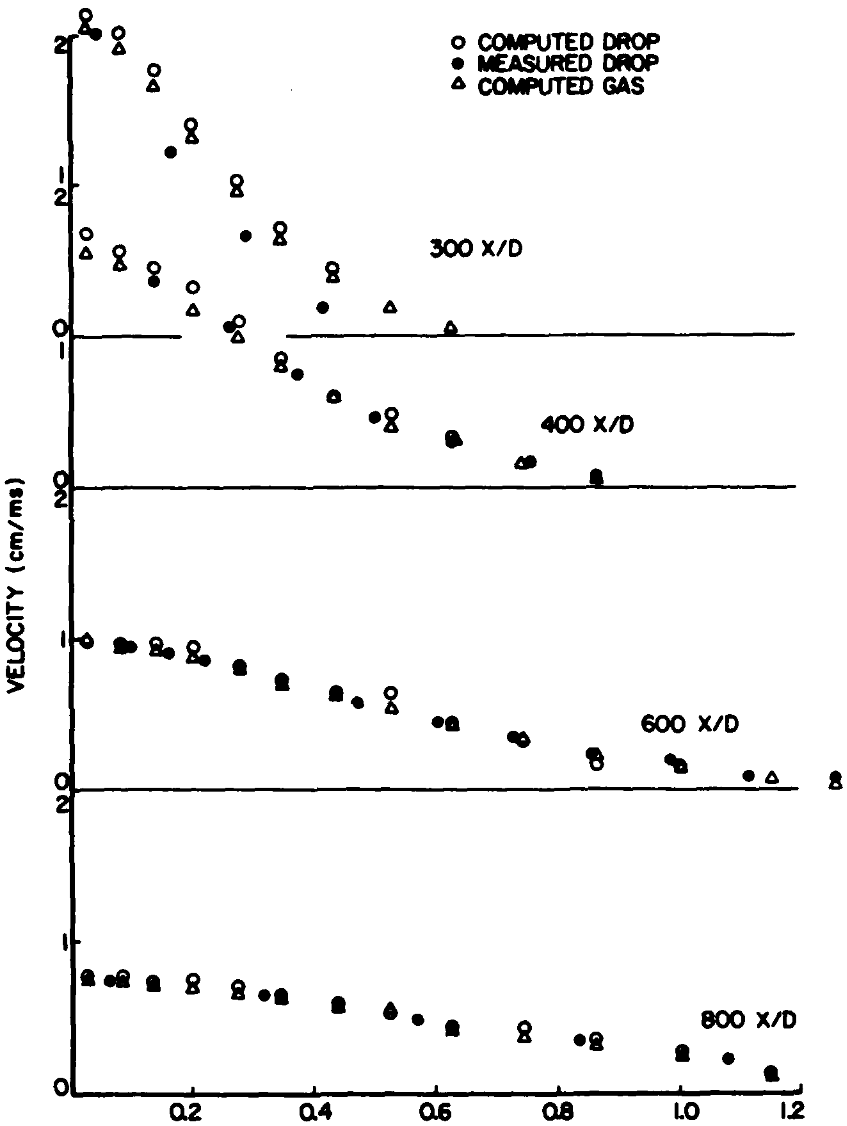


FIG. 10

The model is for fully coupled two-dimensional unsteady two-phase flows and attempts to account for the effect of gas volume fraction on mass momentum and energy transfer rates between the two phases, for drop collisions and coalescence, and for turbulence effects on drops and gas [8]. Typical computed spray structures are shown in Fig. 9: a) drop parcels and gas velocity of a non-evaporating spray; b) gas temperature and vapor mass fraction contours of a vaporizing spray [9].

Comparisons of computed and measured quantities are shown in Figs. 10-16. The parameters of this spray are given in the first row of Table 1. The computed mean axial velocity of the drops agrees reasonably well with the measured one at all radial and axial locations (Fig. 10). Correspondingly there is

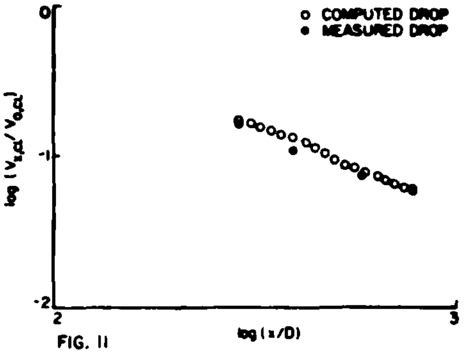


FIG. 11

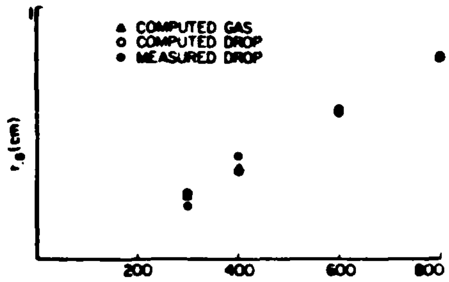


FIG. 12

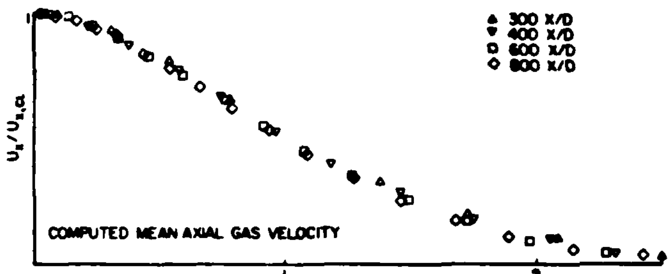


FIG. 13

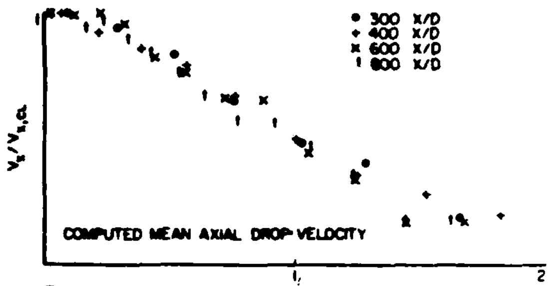


FIG. 14

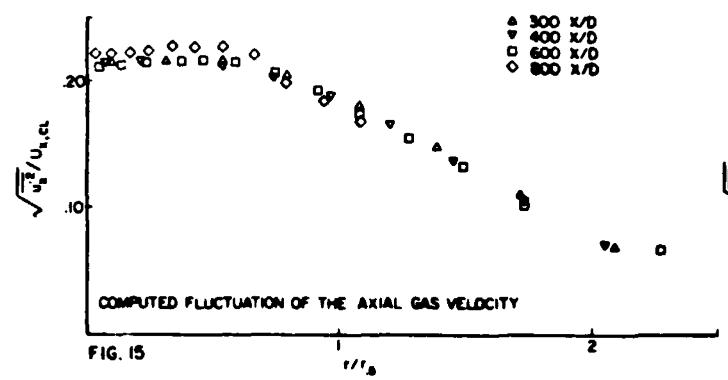


FIG. 15

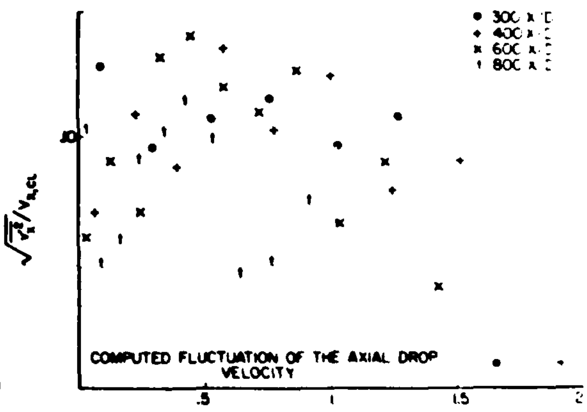


FIG. 16

good agreement also in the centerline velocity decay (Fig. 11) and the spray half-width (Fig. 12). In the computations, as in the experiment, the mean axial velocity of the drops achieves a self similar profile (not imposed a priori) and so does the mean axial velocity of the gas (not measured). The mean values of the drop and gas velocities are computed to be nearly equal (Figs. 10, 13, 14) even though no restrictions were imposed on them a priori. Fig. 15 shows that the computed turbulent fluctuations of the axial component of the gas velocity are close in distribution and magnitude to those measured in the far field of incompressible jets (a k-ε model for the gas turbulence is used in the model). But the computed fluctuations of the axial component of the drop velocity are about a half the measured ones (compare Fig. 16 and 6).

CONCLUSIONS

The breakup of the outer surface of fuel jets in Diesel-type conditions starts in the immediate vicinity of the injector and yields initial spray angle and drop sizes that can be estimated with acceptable accuracy. The mode of breakup of the core of the fuel jet is still unknown.

A non-vaporizing steady spray attains the typical self preserving structure of turbulent jets some 300 nozzle diameters, i.e. 3 to 12 cm, from the injector probably because at that distance most of the jet mass is entrained mass. Mean drop and gas velocities are then nearly equal but their fluctuating components are very large ($\approx$ 30%) and not necessarily in phase. Vaporizing sprays should develop closer to the injector since the axial length scale decreases with decreasing (effective) density of the injected fluid. Even so, the development region remains the one of prime interest in engine applications, particularly since the properties of the ambient gas change during the propagation of the spray.

A recently developed model for transient sprays has reproduced satisfactory all measured downstream steady mean properties but not the fluctuation of the axial component of the drop velocity. The steady far field was obtained integrating through the transient and the development region. The good agreement with the steady farfield does not prove that the transient and the development regions themselves are reproduced accurately, but it lends support to such possibility. Moreover earlier comparisons with nearfield tip penetration rates and far field drop size measurements in different conditions were also satisfactory [7]. In all, so far the model has performed above expectations, but the discrepancy in the fluctuation of the drop velocity points to the need for refinements.

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QUESTIONS

1) Could cavitation contribute to smoke?

2) What of swirl is useful?

3) Is swirl really necessary?

4) Should hollow-cone sprays be reconsidered for open chamber Diesels?

5) Shouldn't ignition be controlled?

WALL EFFECTS ON COMBUSTION IN AN ENGINE

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ABSTRACT

Previous work quantified that flame quenching occurs near a cold wall, whereas rapid conversion of reactants to products occurs near a hot wall. Simple modeling and laboratory experiments are again used to elucidate aspects of flame-wall interaction in an intermittent-burning ICE.

In a premixture, compressive heating of the residual charge may cause so rapid homogeneous combustion (instead of smooth flame propagation) that spatially inhomogeneous pressure occurs ("end-gas knock"). Analysis suggests that augmented heat transfer from the end gas precludes explosive burning, though a larger fraction of the charge than often envisioned must be regarded as "end gas." Recent emphasis on chamber shape in reciprocating-piston engines is well taken, since knock-free operation of production carburetored engines at compression ratio of 12.5 has been demonstrated.

Also to be presented are temperature and fuel mass fraction measurements obtained by laser Raman spectroscopy for sidewall quenching (placing a cold plate perpendicular to a burner-stabilized, planar, premixed flame). These measurements indicate the (1) residual fuel near the cold sidewall is rapidly oxidated (so crevice-type quenching is the predominant source of exhaust hydrocarbons), and (2) there is sufficient sensitivity to quench-surface material and to hydrocarbon species that simplistic aerothermochemical models afford only qualitative guidance.

These two studies suggest that, by design for heat transfer and chamber geometry, smooth yet complete charge burn-up seems attainable.

HEAT TRANSFER AND END-GAS KNOCK

- HIGH CR IMPLIES HIGH THERMAL EFFICIENCY IN LEAN-BURN OTTO-CYCLE ICE
- HIGH CR IMPLIES END-GAS KNOCK (EXPLOSIVE BURNING OF FINAL CHARGE FROM COMPRESSIVE PREHEATING
- CHEMICALLY-KINETIC APPROACHES ENVIRONMENTALLY CONSTRAINED (LEAD ALKYL ADDITIVES SUCH AS $Pb(C_2H_5)_4$)
- MECHANICAL-ENGINEERING APPROACHES (HEAT TRANSFER FROM END GAS VIA COMBUSTION CHAMBER LAYOUT--PORSCHE 944)

SIMPLISTIC MODELING APPROACH

QUESTION: CAN ENHANCED HEAT TRANSFER FROM THE END GAS (E.G., BY LARGE SURFACE-TO-VOLUME GEOMETRY) PERMIT SMOOTH FLAME PROPAGATION INSTEAD OF EXPLOSION?

- o CONSIDER A SPATIALLY HOMOGENEOUS COMBUSTIBLE PREMIXTURE: WHAT TEMPERATURE OF THE END GAS RESULTS IN CHEMICAL CONVERSION ON A TIME SCALE SHORTER THAN THE ACOUSTIC TIME SCALE (SO A SPATIAL INHOMOGENEITY ARISES IN THE PRESSURE FIELD)?

  ---CHEMICAL-KINETIC CALCULATION

- o WHAT HEAT TRANSFER SUFFICES TO REDUCE END-GAS TEMPERATURE SO VERY RAPID CHEMICAL CONVERSION IS PREVENTED?

  ---NONISOBARIC ONE-DIMENSIONAL THIN-FLAME CALCULATION

THIN-FLAME MODEL OF NONISOBARIC COMBUSTION

- PRESSURE p FUNCTION OF TIME t ONLY, $p(t)$
- INDEFINITELY THIN ONE-DIMENSIONAL FLAME $x_f(t) \Longleftrightarrow \Psi(t)$ WHERE $d\psi = \rho A(x,t)dx$
- FLAME PROPAGATION SPEED RELATIVE TO GAS GIVEN: FOR EXAMPLE, $w(p/p_o) = w_o(p/p_o)^T$
- EACH ELEMENT OF BURNED GAS UNDERGOES ADIABATIC COMPRESSION, BASED ON THE STATE OF THAT ELEMENT AT COMBUSTION
- EACH ELEMENT OF UNBURNED GAS UNDERGOES ADIABATIC COMPRESSION BASED ON A UNIFORM INITIAL STATE (SPATIALLY UNIFORM)
- A FRACTION OF THE UNBURNED GAS (THE END GAS) IS DESCRIBED BY A DISTINCT POLYTROPIC LAW BASED ON A UNIFORM (BUT POSSIBLY DISTINCT) INITIAL STATE (SPATIALLY UNIFORM)

SIDE-WALL BOUNDARY/EIGENVALUE PROBLEM

- DIRECT ONE-STEP IRREVERSIBLE REACTION (O = OXYGEN, F = FUEL, P = PRODUCT)

$$\nu_O O + \nu_F F \rightarrow \nu_P P \text{ (ARRHENIUS KINETICS)}$$

- MOLECULAR WEIGHT OF MAJOR SPECIES COMPARABLE
- UNIVERSAL BINARY DIFFUSION COEFFICIENT
- LEWIS-SEMENOV NUMBER UNITY
- ISOBARIC LOW-MACH-NUMBER FLOW (NO MECHANICAL DISSIPATION)
- CONSTANT UNIVERSAL SPECIFIC HEAT
- SIMPLE VARIATION OF TRANSPORT PROPERTIES WITH THERMODYNAMIC STATE
- DECOUPLING OF THE DYNAMICS AND ENERGETICS (APPROXIMATION OF FLOW FOR CONVECTIVE TRANSPORT OF HEAT AND SPECIES)

HOMOGENEOUS EXPLOSION OF A PREMIXTURE

ADOPT

$$\nu_0\, 0 + \nu_F\, F \rightarrow \text{PRODUCTS}$$

LEWIS NUMBER UNITY

FUEL-LEAN OR STOICHIOMETRIC ($\phi \leq 1$)

$$T_f^* = T_u^* + \frac{Q_f^*}{c_p^*}\,\frac{m^* Y_{F_u}}{m_F^*\,\nu_F}\ ,\quad m^* = m_0^*\,\nu_0 + m_F^*\,\nu_F$$

$$\phi = \frac{\left(Y_{F_u}/Y_{0_u}\right)}{\left(m_F^*\,\nu_F \,/\, m_0^*\,\nu_0\right)}\ ,\quad \beta = \frac{\theta^*}{T_f^* - T_u^*}\ ,\quad t = \frac{u_u^{*2}\,t^*}{D_u^*}\ ,$$

$$T = \frac{T^* - T_u^*}{T_f^* - T_u^*}\ ,\quad T_0 = \frac{T_0^* - T_u^*}{T_f^* - T_u^*}\ ,\quad \eta^2 \text{ "EIGENVALUE"}$$

$$\frac{dT}{dt} = \eta^2\left[1 + T_0 - T\right]^{\nu_F}\left[(1 - \phi) + \phi\,\{1 + T_0 - T\}\right]^{\nu_0} e^{\frac{-\beta}{T}(1-T)}$$

$$T(0) = T_0\ ,\quad T(t_f) \equiv 1 + T_0$$

<u>SEEK</u> T_0^* SUCH THAT $t_f^* < \dfrac{2.54\ \text{CM}}{a_0^*}$, $a_0^* = (\gamma R^*\, T_0^*)^{1/2}$

TAYLOR: $T_0^* = 0(1000\ \text{K})$

USE OF POLYTROPIC LAW TO MODEL HEAT TRANSFER

$$c_v \frac{dT}{dt} + p \frac{d(1/\rho)}{dt} = q = \text{RATE OF HEAT ADDITION (PER UNIT MASS)}$$

IDEAL GAS:

$$\frac{d\ \ln T}{dt} - (\gamma - 1)\frac{d\ \ln \rho}{dt} = \frac{d(\ln p)}{dt} - \gamma \frac{d(\ln \rho)}{dt} = \frac{q}{c_v T}$$

IF $q = -\varepsilon\, c_v\, T$, ε CONST. ,

$$\frac{d\ \ln (p/\rho^\gamma)}{dt} = \varepsilon \Rightarrow \frac{p}{\rho^\gamma} = \frac{p_0}{\rho_0{}^\gamma} \exp(-\varepsilon t)$$

IF $(p/p_0) = \exp(\mu t)$ DURING COMBUSTION,

I.E., IF $\exp(-\varepsilon t) = (p/p_0)^{-\varepsilon/\mu}$,

THEN

$$\frac{\rho}{\rho_0} = \left(\frac{p}{p_0}\right)^{1/\gamma^*} , \quad \frac{1}{\gamma^*} = \frac{1}{\gamma}\left(1 + \frac{\varepsilon}{\mu}\right) \Rightarrow \gamma > \gamma^*$$

$\therefore$, HEAT LOSSES CAN BE MODELLED VERY CRUDELY, BUT VERY ADEQUATELY FOR CURRENT PURPOSES BY USE OF A γ WHICH IS LESS THAN c_p/c_v.

THERMODYNAMICS

INVERSE FUNCTION: $p_1(\psi) \longleftrightarrow \Psi(p)$

BULK GAS $(0 < \psi < \psi_2)$

UNBURNED GAS $(\psi > \Psi)$:

$$\rho_u/\rho_0 = (p/p_0)^{1/\gamma}$$

$$h_u/h_0 = (p/p_0)^{\alpha}, \quad \alpha = 1 - \frac{1}{\gamma}$$

JUST-BURNED GAS $(\psi = \Psi -)$:

$$h_{J\text{-}B}/h_0 = (p/p_0)^{\alpha} + (H/h_0)$$

$$\rho_{J\text{-}B}/\rho_0 = \frac{p/p_0}{\left(\frac{p}{p_0}\right)^{\alpha} + \frac{H}{h_0}}$$

BURNED GAS $(\psi < \Psi)$:

$$\rho_B/\rho_0 = \frac{p_1(\psi)/p_0}{\left(\frac{p_1(\psi)}{p_0}\right)^{\alpha} + \frac{H}{h_0}} \left(\frac{p}{p_1(\psi)}\right)^{1/\gamma}$$

END GAS $(\psi_2 < \psi < m)$

UNBURNED GAS $(\psi > \Psi)$:

$$\rho_u'/\rho_0' = (p/p_0)^{1/\kappa}$$

$$h_u'/h_0' = (p/p_0)^{\beta}, \quad \beta = 1 - \frac{1}{\kappa}$$

JUST-BURNED GAS $(\psi = \Psi -)$:

$$h_{J\text{-}B}'/h_0' = (p/p_0)^{\beta} + (H/h_0')$$

$$\rho_{J\text{-}B}'/\rho_0' = \frac{p/p_0}{\left(\frac{p}{p_0}\right)^{\beta} + \frac{H}{h_0'}}$$

BURNED GAS $(\psi < \Psi)$:

$$\rho_B'/\rho_0' = \frac{p_1(\psi)/p_0}{\left(\frac{p_1(\psi)}{p_0}\right)^{\beta} + \frac{H}{h_0'}} \left(\frac{p}{p_1(\psi)}\right)^{1/\kappa}$$

SIDE-WALL ELLIPTICAL PARTIAL DIFFERENTIAL EQUATIONS

$$0 \leqslant x \leqslant x_t,\ 0 \leqslant z \leqslant L$$

$$\rho u \frac{\partial Y}{\partial x} + \rho v \frac{\partial Y}{\partial z} - \left(\frac{\partial^2 Y}{\partial x^2} + \frac{\partial^2 Y}{\partial z^2}\right) = -\eta^2\ Y^{\nu_F}\left[(1 - \phi) + \phi Y\right]^{\nu_0} \exp\left[-\frac{\beta}{T}(1 - T)\right]$$

$$\rho u \frac{\partial T}{\partial x} + \rho v \frac{\partial T}{\partial z} - \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial z^2}\right) = \eta^2\ Y^{\nu_F}\left[(1 - \phi) + \phi Y\right]^{\nu_0} \exp\left[-\frac{\beta}{T}(1 - T)\right]$$

$$\eta^2 = \frac{B_f^* m^* \rho^* D^* Y_{F_u}^{\nu_F+\nu_0-1}\ \phi^{-\nu_0} \exp(-\beta)}{\dot{m}^{*2}} \doteq \beta^{1+\nu_F}\left[2(1 - \phi)^{\nu_0}\ \Gamma(\nu_F + 1)\right]^{-1}$$

$$\rho u \text{ SPECIFIED; } \rho v = -\frac{d}{dx}\int_0^z \rho u\, dz$$

BOUNDARY CONDITIONS

$x = 0$: $\rho u = C$, $\rho v = 0$, $T = T_0$, $Y = 1 - T_0$ WHERE $1 \gg T_0 > 0$

$x = x_t$: $\dfrac{\partial^2 T}{\partial x^2} = \dfrac{\partial^2 Y}{\partial x^2} = 0$

$Z = L$: $\dfrac{\partial(\rho u)}{\partial z} = \dfrac{\partial T}{\partial z} = \dfrac{\partial Y}{\partial z} = \rho v = 0$ FOR TWO-WALL DUCT

$$\left.\begin{array}{l} C\dfrac{dY}{dx} - \dfrac{d^2Y}{dx^2} = -\eta^2 Y^{\nu_F}\left[(1-\phi) + \phi Y\right]^{\nu_0} \exp\left[-\dfrac{\beta}{T}(1-T)\right] \\ Y = Y_0 \text{ AT } x = 0;\ \dfrac{\partial Y}{\partial x} = 0 \text{ AT } x = x_t;\ T + Y = 1 \end{array}\right\} \begin{array}{l}\text{FOR}\\ \text{ONE}\\ \text{WALL,}\\ L >> 1\end{array}$$

$Z = 0$: $T = T_w$ WHERE $1 \geq T_w \geq T_0$, $\dfrac{\partial Y}{\partial z} = 0$ FOR ISOTHERMAL NONCATALYTIC WALL

$\dfrac{\partial T}{\partial z} = \dfrac{\partial Y}{\partial z} = 0$ FOR ADIABATIC NONCATALYTIC WALL

$T = T_0$, $Y = 1 - T_0$ FOR ISOTHERMAL POROUS WALL

PISTON-CRANK RELATIONSHIP

PISTON DISPLACEMENT FROM INITIAL POSITION

$$y(t) = D(0) - D(t)$$

$$D(t) = \underbrace{\frac{2r}{(CR)-1}}_{\text{CLEARANCE AT TDC}} + \underbrace{r\left[1 - \cos\theta + R_a\left\{1 - \left[1 - \left(\frac{\sin\theta}{R_a}\right)^2\right]^{\frac{1}{2}}\right\}\right]}_{\text{DISPLACEMENT FROM CLEARANCE AT TDC}}$$

θ = CRANK ANGLE = $2\pi nt + \theta_0$, n = RPM

r = CRANK RADIUS

R_a = ℓ/r , ℓ = CONNECTING-ROD LENGTH

CR = COMPRESSION RATIO

EQUATIONS

$\underline{\psi_2 > \Psi(t) > 0}$	$\underline{m > \Psi(t) > \psi_2}$
$p(t), \Psi(t), x_f(t), x_2(t)$	$p(t), \Psi(t), x_f(t)$

FLAME-PROPAGATION RELATION [$\Psi(0) = 0$]:

$$\dot{\Psi} = \rho_u \, A(x_f, t) \, w \qquad\qquad \dot{\Psi} = \rho_u' \, A(x_f, t) \, w$$

CONTINUITY OF UNBURNED MASS:

$$\rho_u' \int_{x_2(t)}^{L} A(x', t) dx' = m - \psi_2$$

$$\rho_u \int_{x_f(t)}^{x_2(t)} A(x', t) dx' = \psi_2 - \Psi(t)$$

$$\rho_u \int_{x_f(t)}^{L} A(x', t) dx' = m - \Psi(t)$$

GLOBAL CONTINUITY [$V(t) = V_0 - \bar{A} \, y(t)$]:

$$V(t) = \int_0^{\Psi(t)} \frac{d\psi}{\rho_B} + \int_{\Psi(t)}^{\psi_2} \frac{d\psi}{\rho_u} + \int_{\psi_2}^{m} \frac{d\psi}{\rho_u'} \, , \quad V(t) = \int_0^{\psi_2} \frac{d\psi}{\rho_B'} + \int_{\psi_2}^{\Psi(t)} \frac{d\Psi}{\rho_B'} + \int_{\Psi(t)}^{m} \frac{d\psi}{\rho_u'}$$

$$\bar{A} = \pi(B/2)^2 \quad , \quad B = \text{BORE}$$

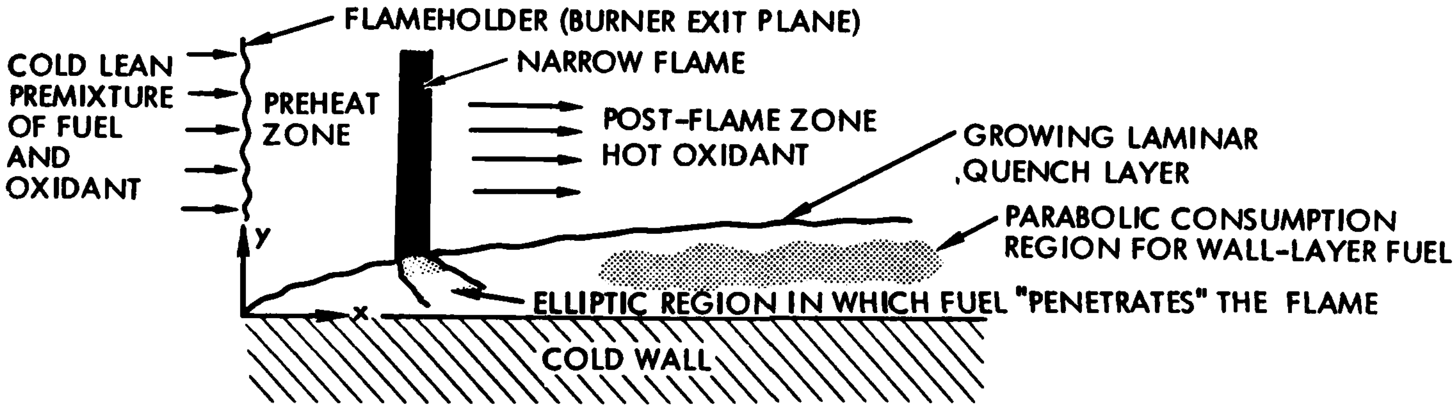
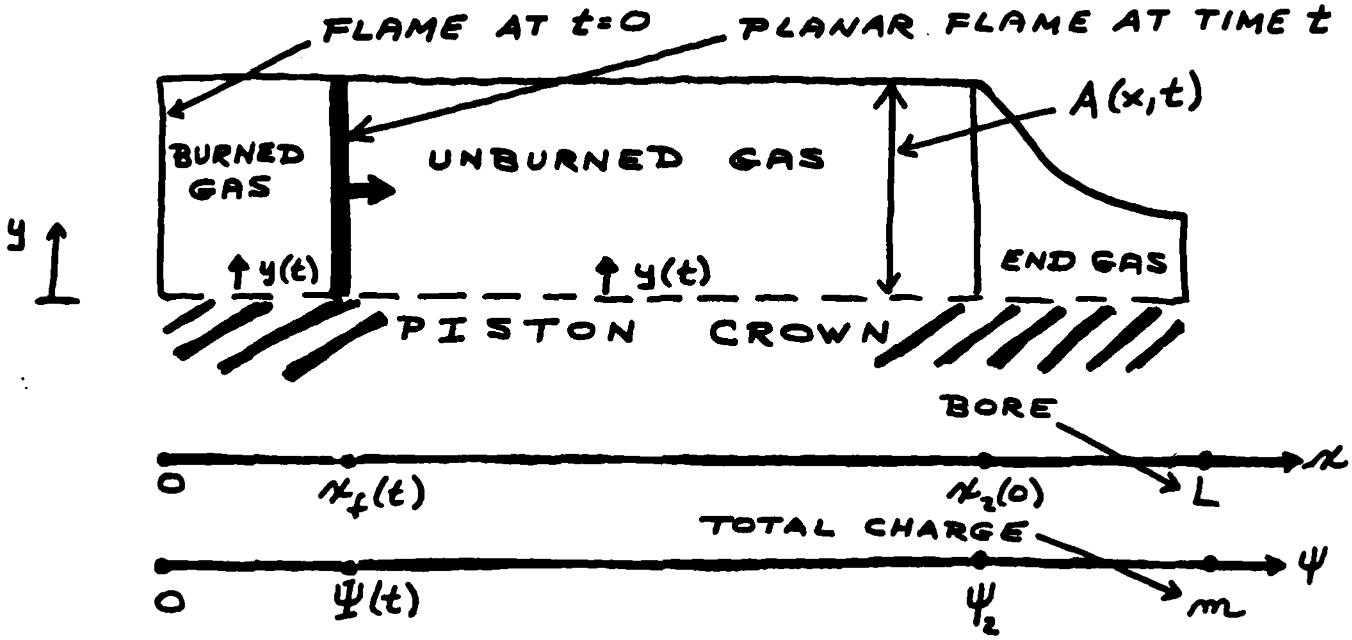


Figure 1 Schematic of the two-dimensional side-wall quench layer beneath a one-dimensional deflagration, stabilized on a heat-sink-type flameholder. The preheat zone has convection and streamwise diffusion; the thin flame, reaction and streamwise diffusion; the postflame combustion-products zone, no diffusion. The upwind elliptical portion of the quench layer has streamwise and transverse diffusion; the downwind parabolic portion of the quench layer, transverse diffusion only.

THREE-ZONE MODEL OF COMBUSTION CHAMBER



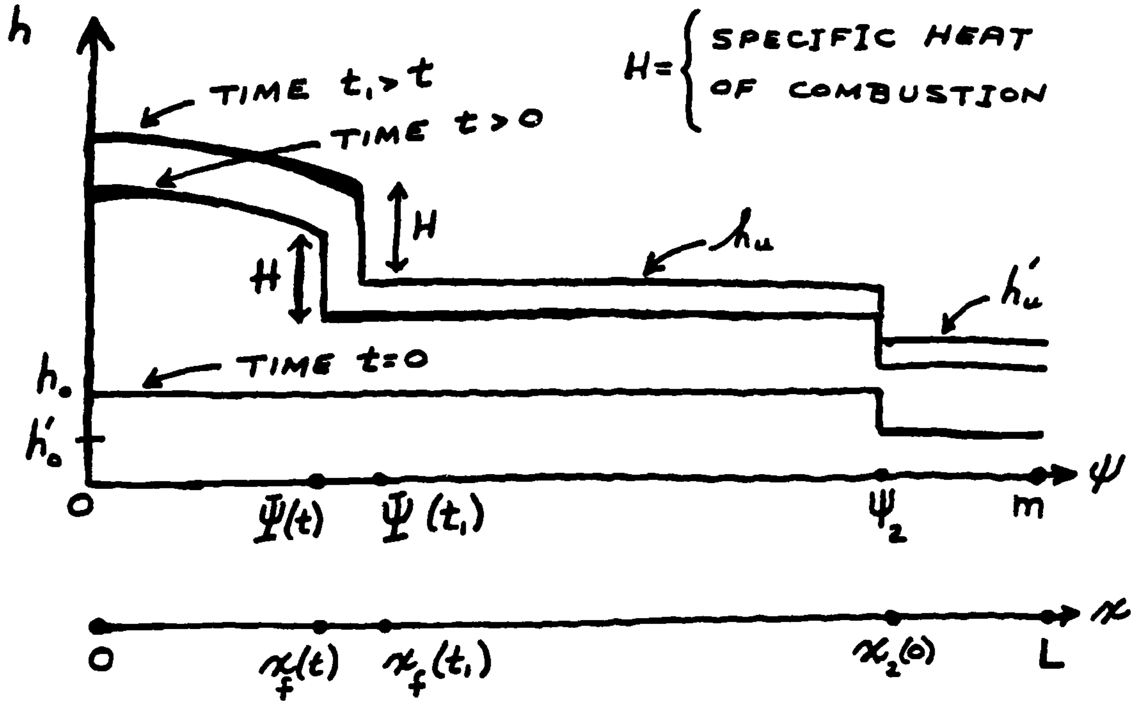
$y(t)$ = PISTON DISPLACEMENT FROM INITIAL POSITION

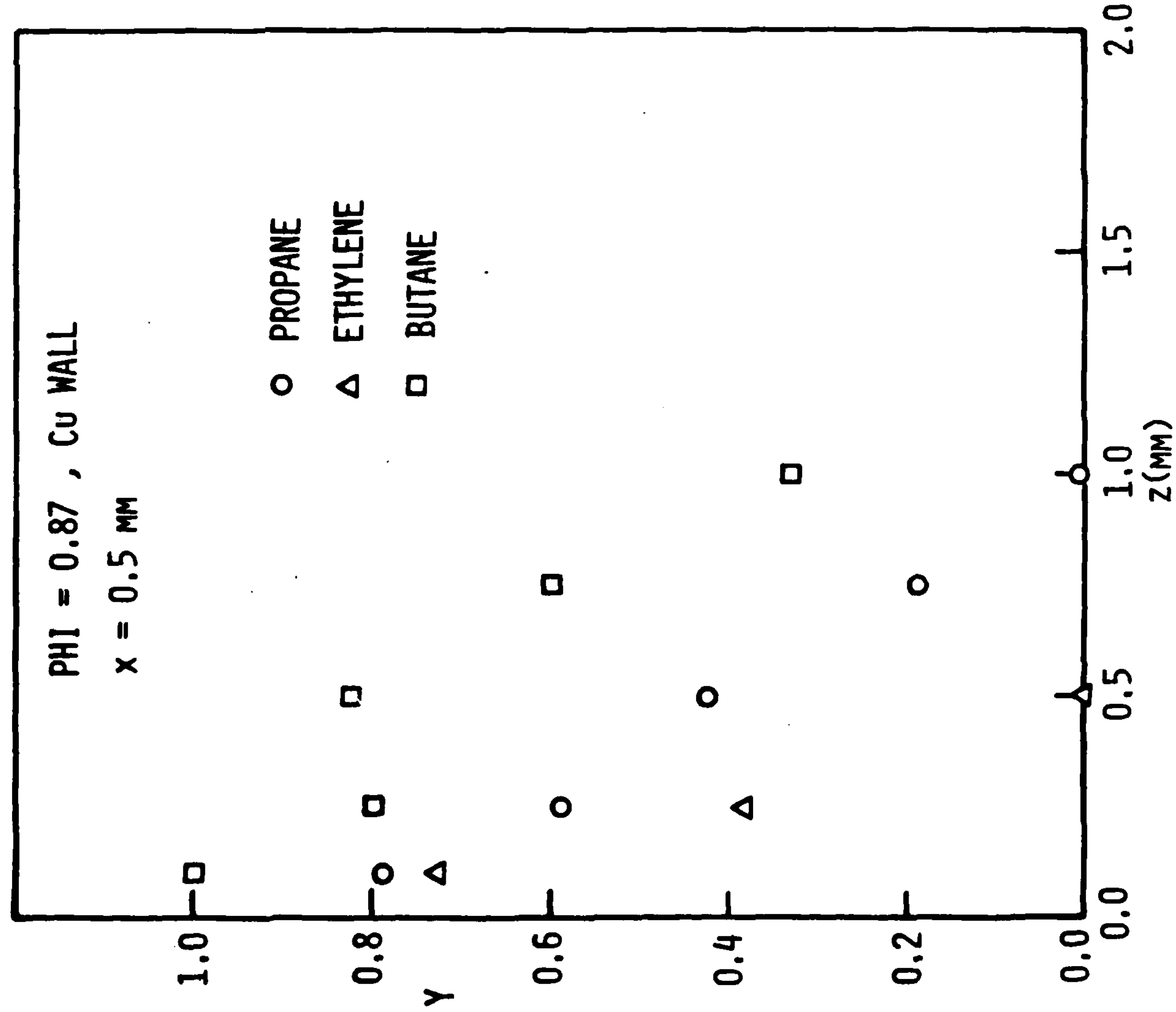
$A(x,t)$ = CHAMBER CROSS-SECTION PARALLEL TO AXIS, FLAME

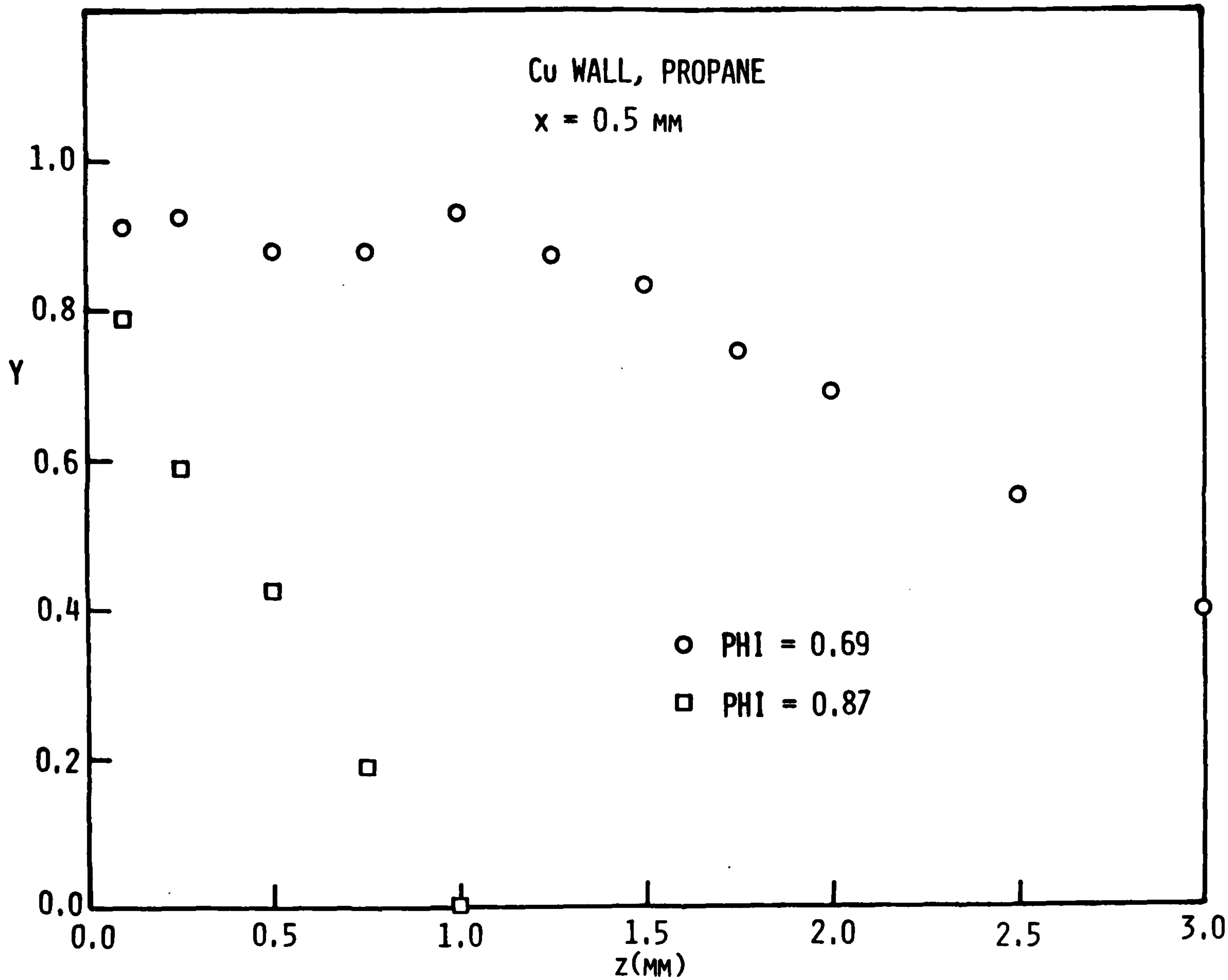
$(m-\psi_2)$ = MASS OF END GAS

ENTHALPY PROFILES

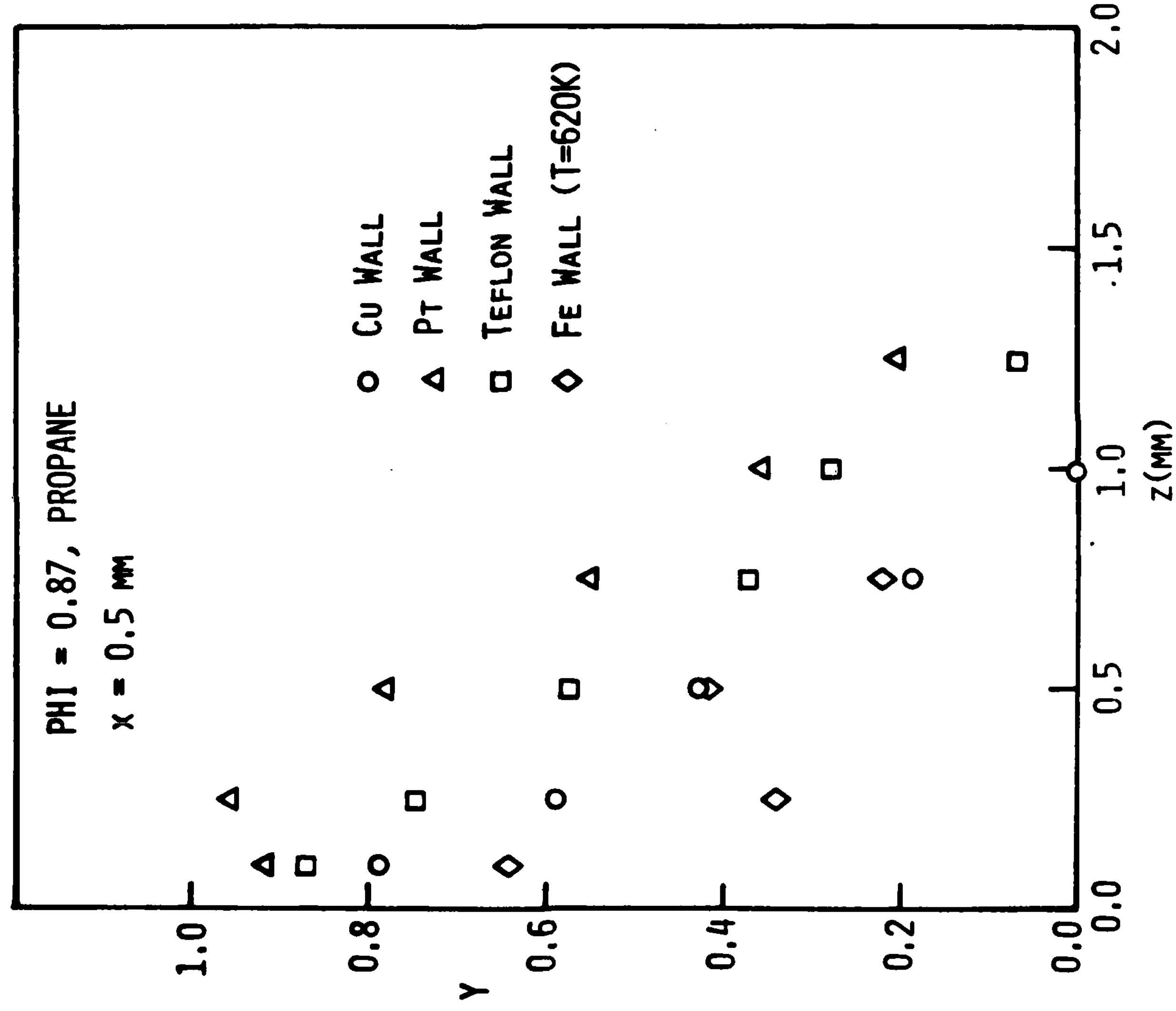
TIME t: $t_1 > t > 0$; PRESSURE $p(t)$: $p(t_1) > p(t) > p_0$

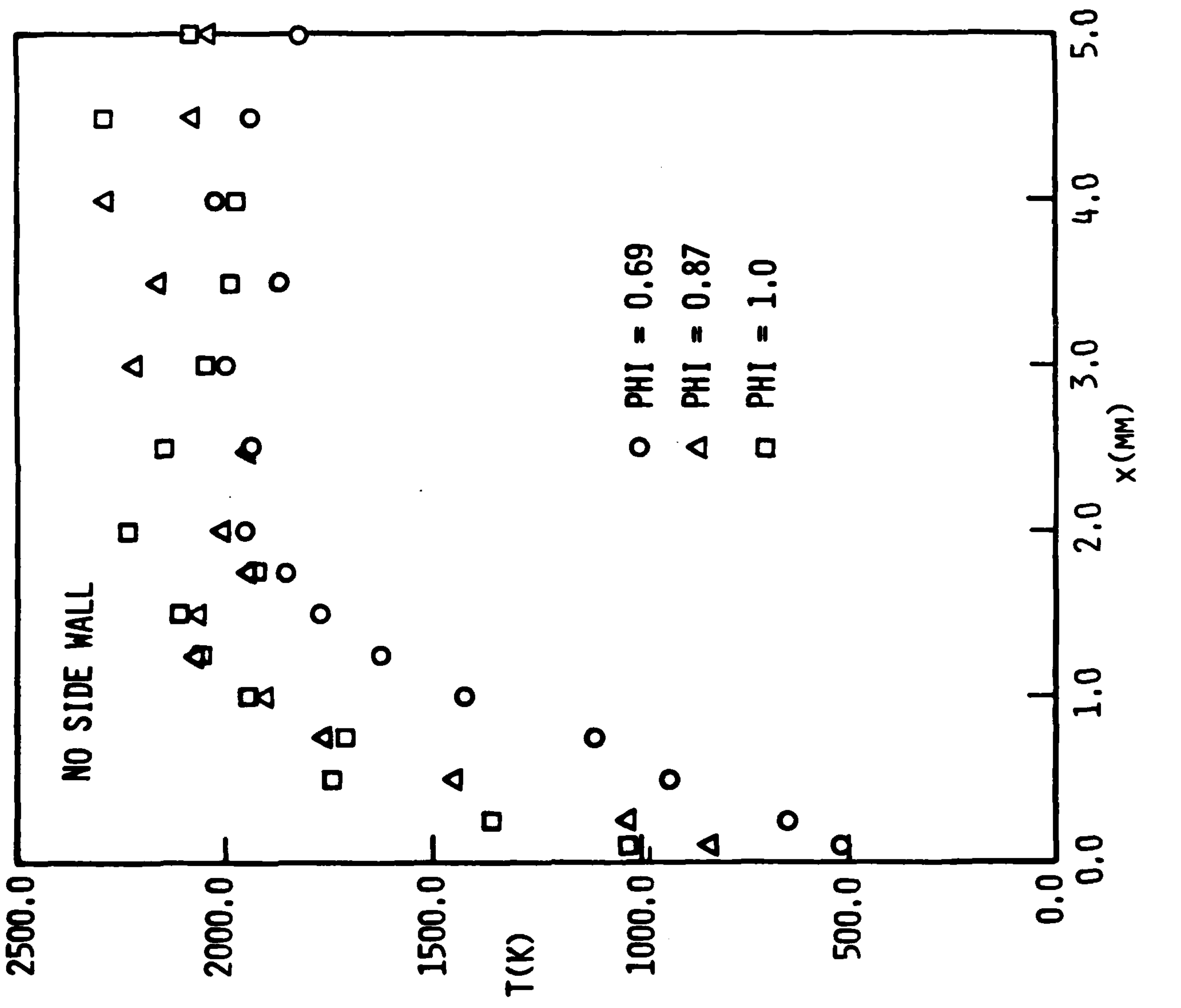


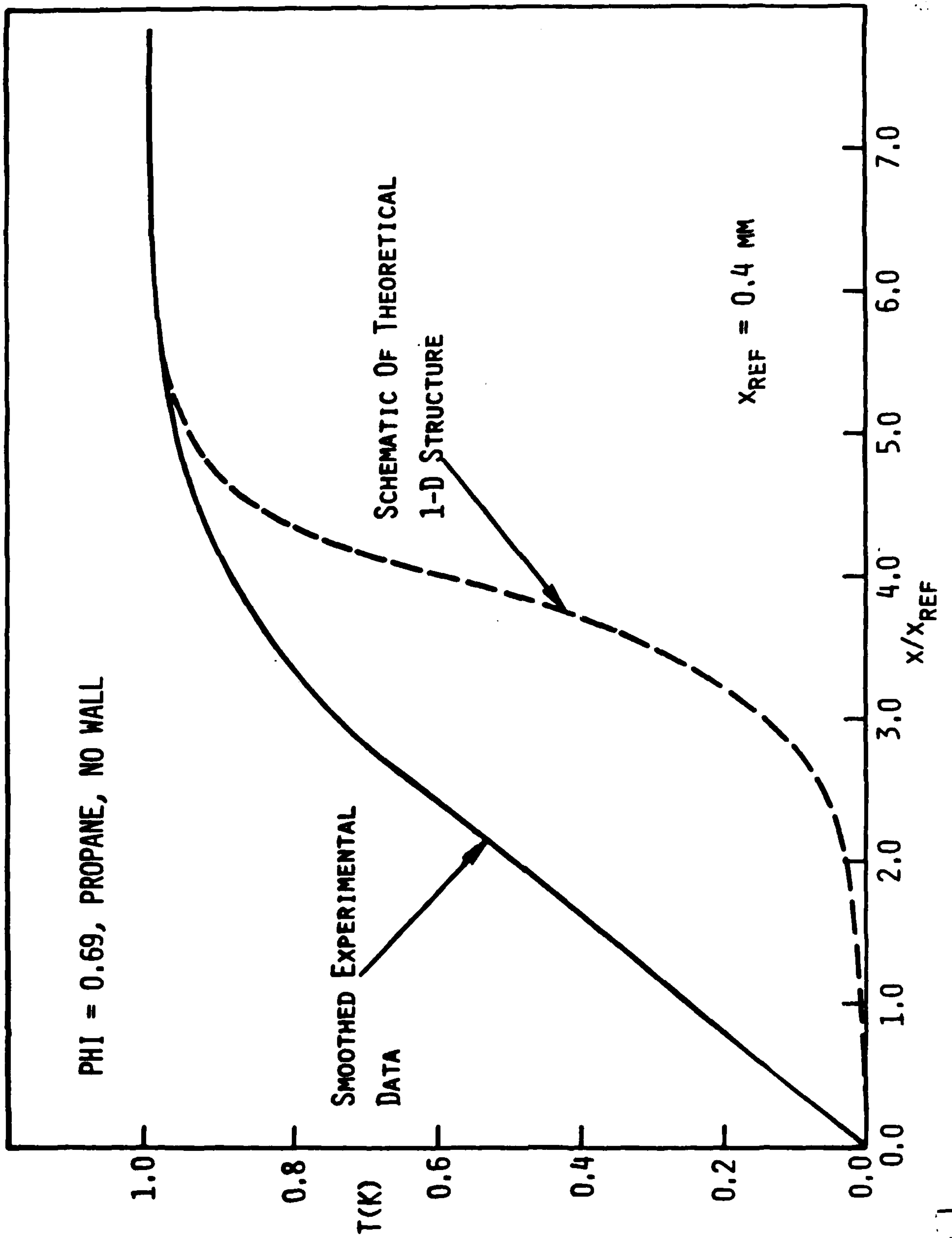

PHI = 0.87 , Cu WALL
x = 0.5 MM
PROPANE
ETHYLENE
BUTANE
Y
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.5
1.0
1.5
2.0
Z(MM)

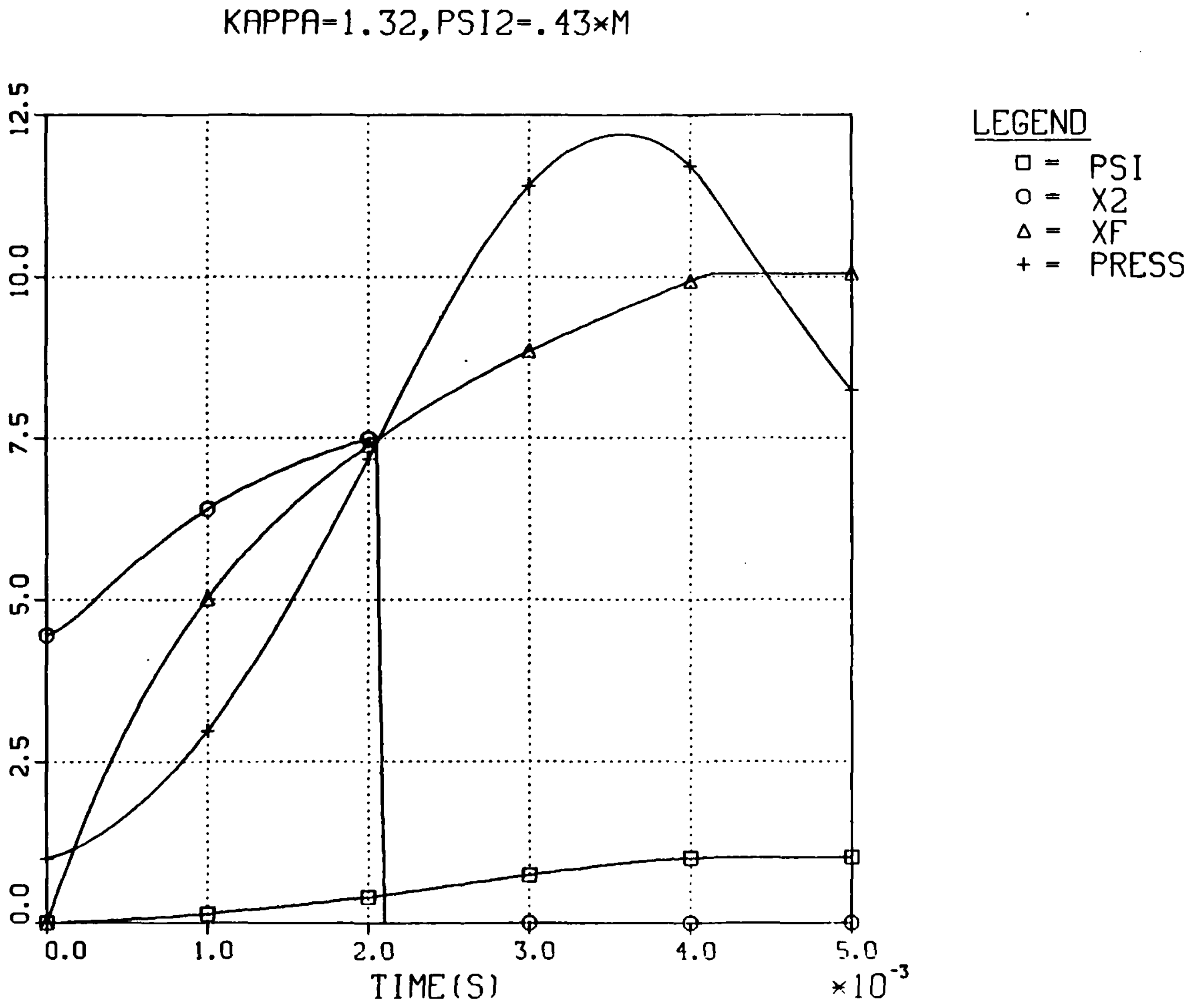


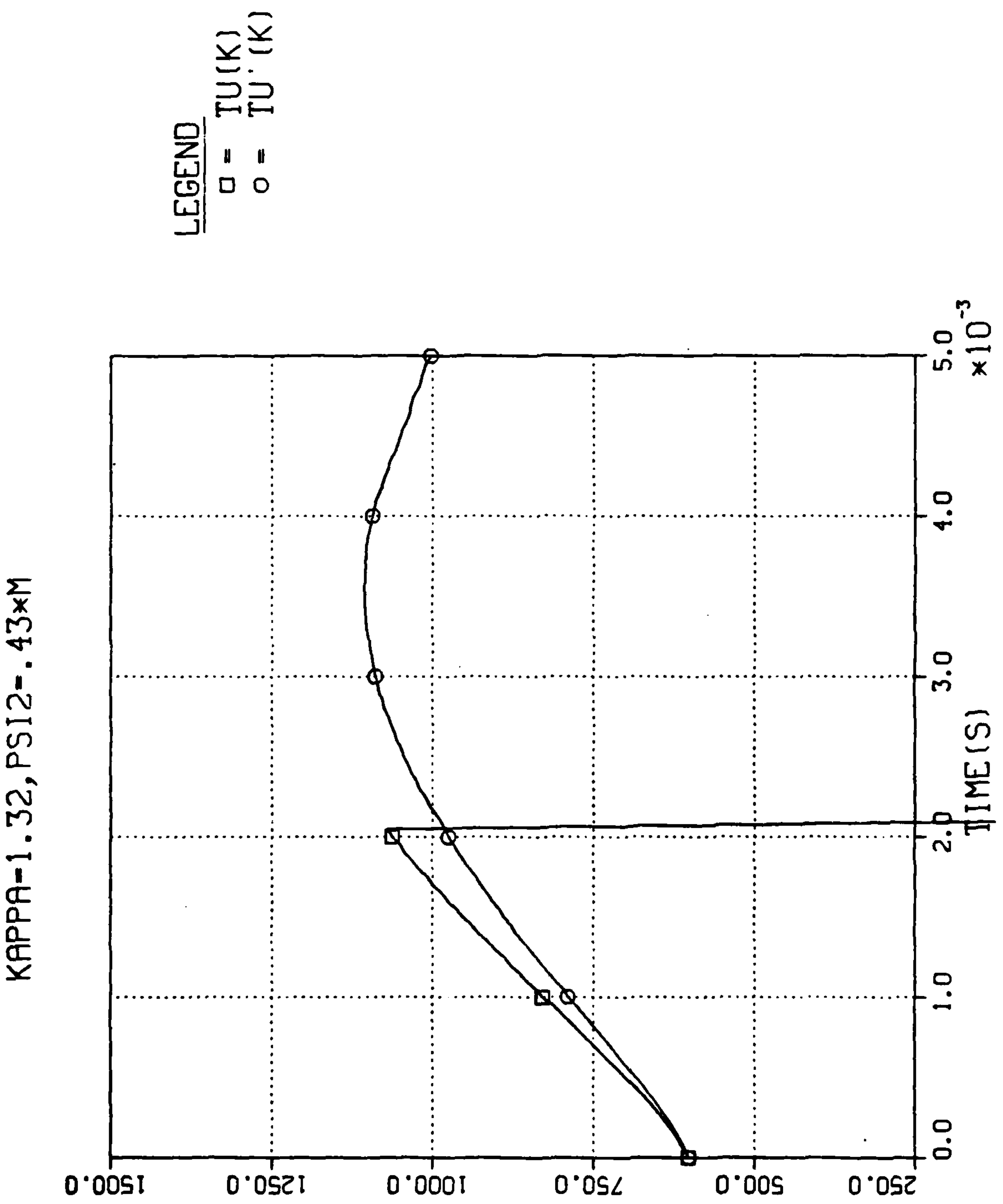
Cu WALL, PROPANE
x = 0.5 MM
1.0
0.8
0.6
0.4
0.2
0.0
Y
0.0
0.5
1.0
1.5
2.0
2.5
3.0
z(MM)
PHI = 0.69
PHI = 0.87


PHI = 0.87, PROPANE
x = 0.5 MM
CU WALL
PT WALL
TEFLON WALL
FE WALL (T=620K)
Y
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.5
1.0
1.5
2.0
z(MM)


NO SIDE WALL
○ PHI = 0.69
△ PHI = 0.87
□ PHI = 1.0
T(K)
x(MM)
0.0
500.0
1000.0
1500.0
2000.0
2500.0
0.0
1.0
2.0
3.0
4.0
5.0


PHI = 0.69, PROPANE, NO WALL
SMOOTHED EXPERIMENTAL DATA
SCHEMATIC OF THEORETICAL 1-D STRUCTURE
X_{REF} = 0.4 MM
T(K)
1.0
0.8
0.6
0.4
0.2
0.0
x/x_{REF}
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0


KAPPA=1.32,PSI2=.43*M
12.5
10.0
7.5
5.0
2.5
0.0
0.0
1.0
2.0
3.0
4.0
5.0
TIME(S)
*10^-3
LEGEND
□ = PSI
○ = X2
△ = XF
+ = PRESS


KAPPA-1.32,PSI2-.43*M
LEGEND
□ = TU(K)
○ = TU'(K)
1500.0
1250.0
1000.0
750.0
500.0
250.0
0.0
1.0
2.0
3.0
4.0
5.0
TIME(S)
*10^-3

"Diesel Engine Cylinder Gas-Side Heat Flux to a Ceramic Surface"

G. L. Borman

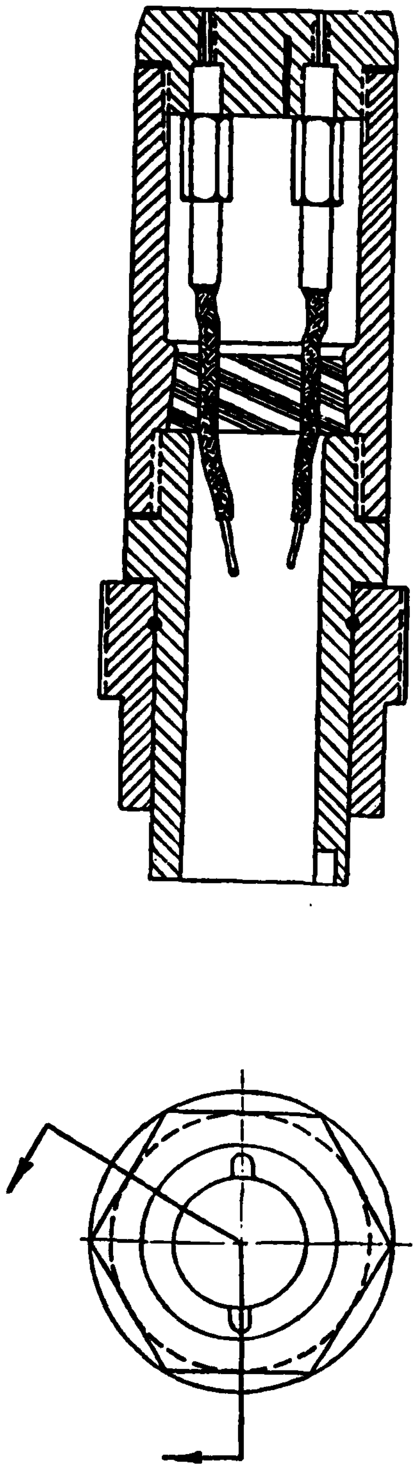
University of Wisconsin — Madison

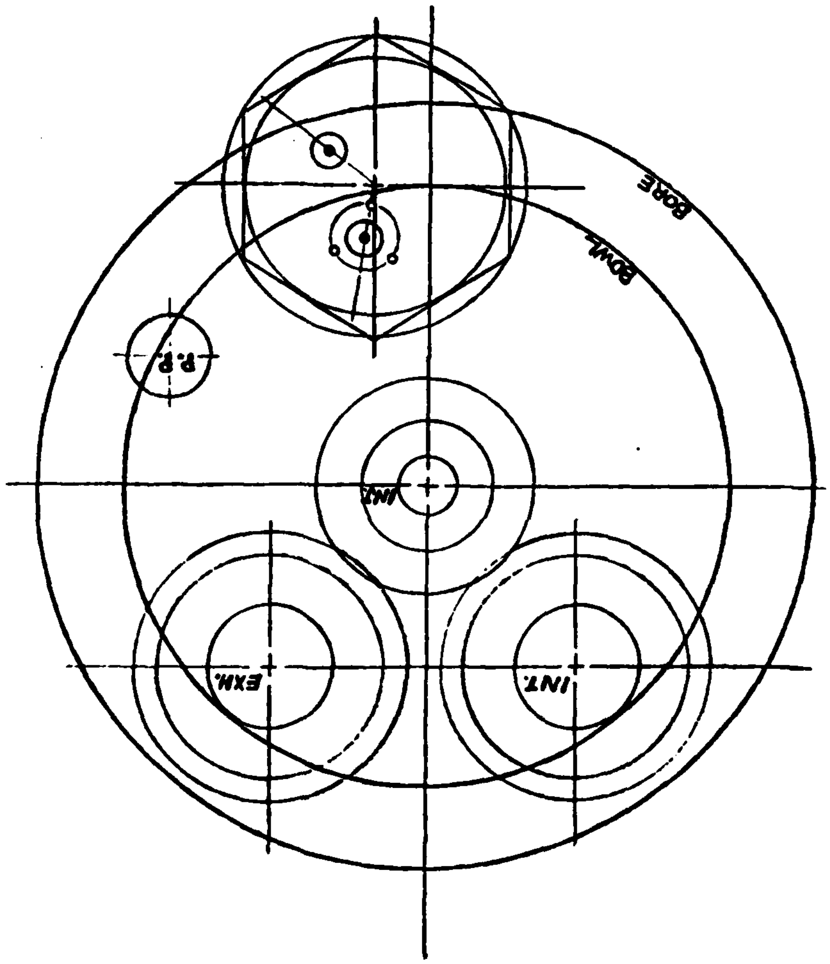
Contract No. DAAG29-81-K-0082

The research effort consists of two projects. The first project is to measure instanteous rates of heat transfer from the cylinder gas to a ceramic surface in a fired diesel engine. The second project is to fabricate and test an instrument which is to measure either the total instanteous heat transfer or only its radiation component in a fired diesel. Both projects will be carried out on a TACOM-LABECO single cylinder, open chamber engine.

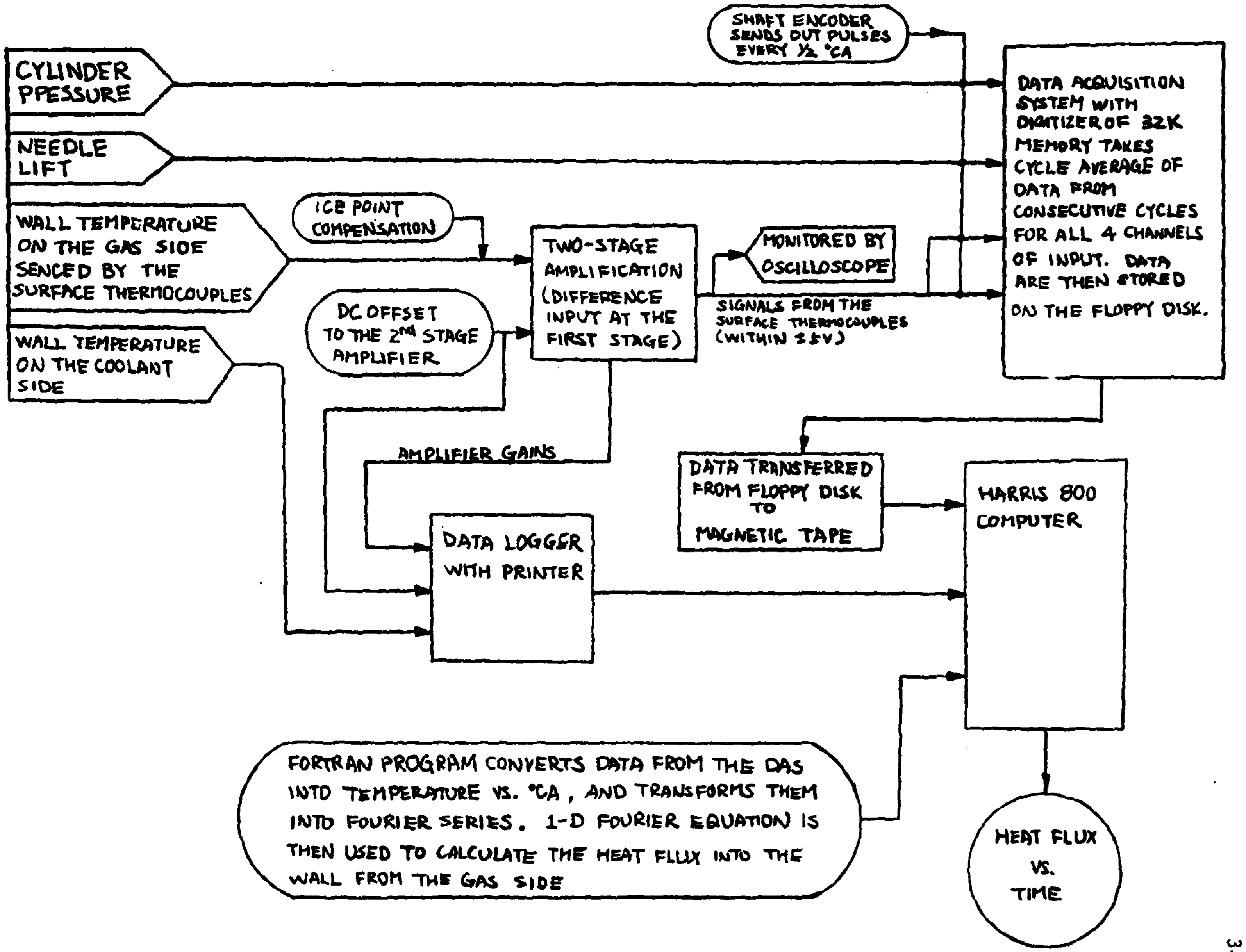
The heat transfer measurements will utilize a specially fabricated head which contains a very large instrumentation plug. The cylinder side surface of this plug is designed to accept plates of various candidate ceramic materials. The two materials to be tested are hot pressed zirconia and a surface sealed layer of porous zirconia. To date, the engine head has been fabricated and is now under preliminary test. Methods of instrumenting the ceramic surfaces have been investigated both in our own lab and from commercial sources. It appears that either thin film thermocouples formed by overlapping films or a platinum resistance film can be used. While the head was being fabricated and the transducer being investigated, a series of base line heat transfer measurements were conducted using a metal head and thin film thermocouples. Methods of recording and processing the data have been developed.

The special heat transfer instrument will utilize a thin film thermocouple to measure either total convective and radiative heat transfer or only the radiative component. When only radiation is to be measured, a timed jet of heated air is directed over the surface thermocouple. Engine testing of the device for feasibility is currently underway.




BORE
BOWL
R.P.
INT.
EXH.
INT.

DATA TAKING AND PROCESSING FLOW CHART



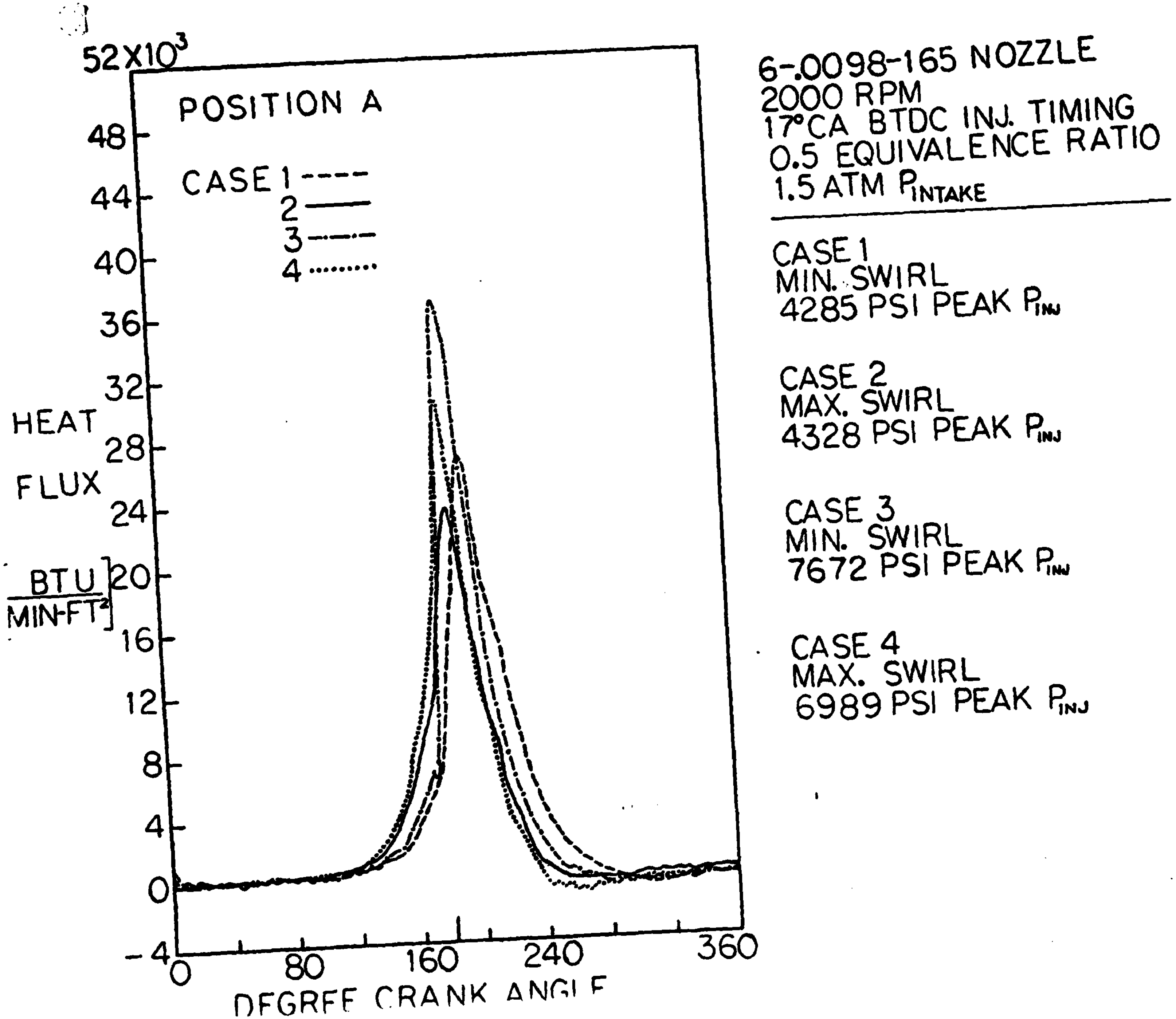
35 RUNNING CONDITIONS

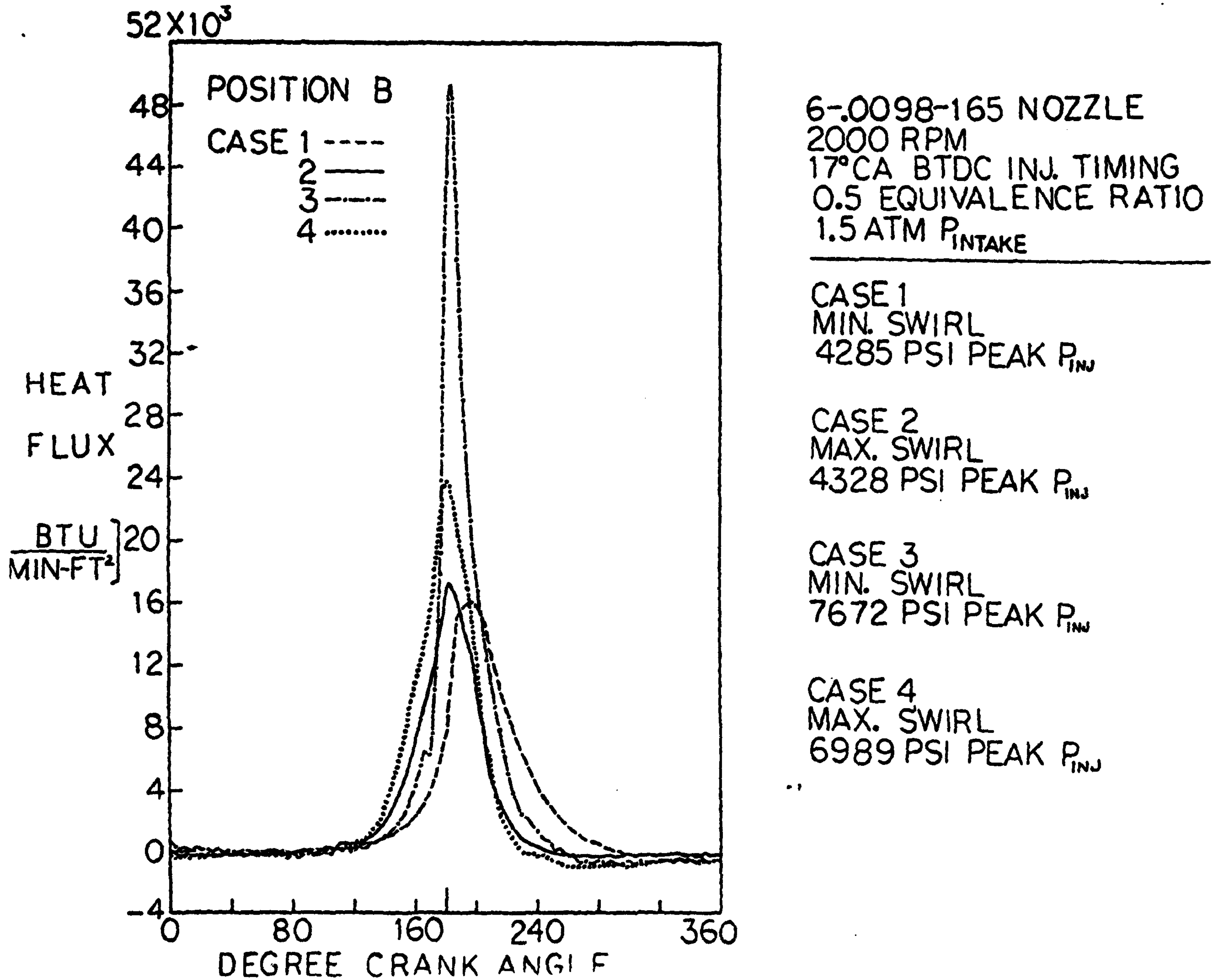
- 4–.0079–155, MIN. SWIRL, $\Phi = 0.5$
  - 5750 PSI PEAK P_{INJ}
    - 10°CA BTDC IJT
    - 17°CA BTDC IJT
    - 23°CA BTDC IJT
    - 30°CA BTDC IJT
  - 11574 PSI PEAK P_{INJ}
    - 10°CA BTDC IJT
    - 17°CA BTDC IJT
    - 23°CA BTDC IJT
    - 30°CA BTDC IJT
  - 12967 PSI PEAK P_{INJ}
    - 10°CA BTDC IJT
    - 17°CA BTDC IJT
    - 23°CA BTDC IJT

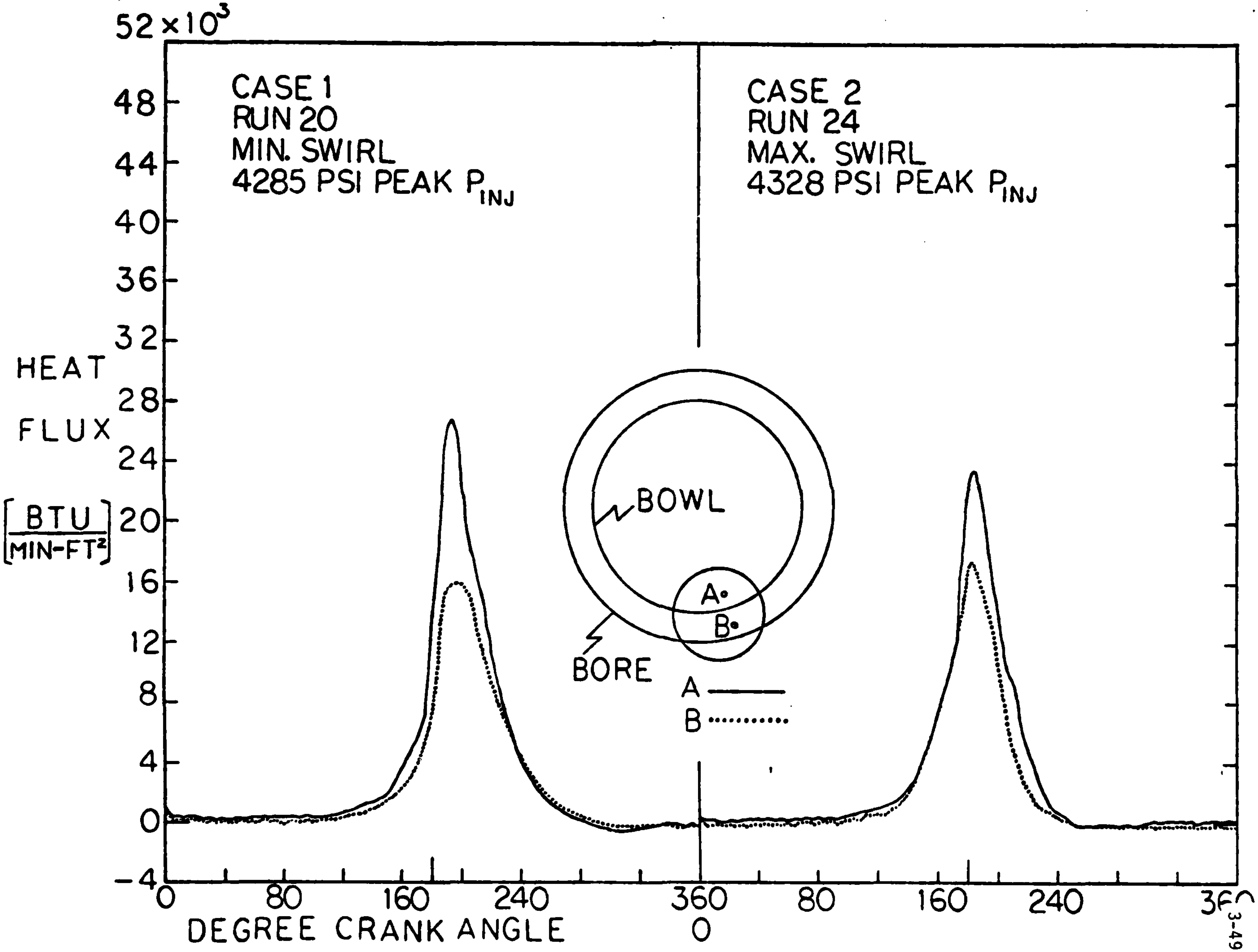
- 6–.0098–165, 17°CA BTDC IJT, $\Phi = 0.5$
  - MIN. SWIRL
    - 4285 PSI PEAK P_{INJ}
    - 6784 PSI PEAK P_{INJ}
    - 7177 PSI PEAK P_{INJ}
    - 7672 PSI PEAK P_{INJ}
    - 8158 PSI PEAK P_{INJ}
    - 8595 PSI PEAK P_{INJ}
  - MAX. SWIRL
    - 4328 PSI PEAK P_{INJ}
    - 5938 PSI PEAK P_{INJ}
    - 6720 PSI PEAK P_{INJ}
    - 6989 PSI PEAK P_{INJ}
    - 8098 PSI PEAK P_{INJ}
    - 8722 PSI PEAK P_{INJ}

- 8–.0096–157, 17°CA BTDC IJT, $\Phi = 0.5$
  - MIN. SWIRL
    - 4653 PSI PEAK P_{INJ}
    - 8034 PSI PEAK P_{INJ}
    - 9560 PSI PEAK P_{INJ}
    - 9668 PSI PEAK P_{INJ}
  - MAX. SWIRL
    - 4610 PSI PEAK P_{INJ}
    - 6316 PSI PEAK P_{INJ}
    - 7490 PSI PEAK P_{INJ}
    - 9600 PSI PEAK P_{INJ}

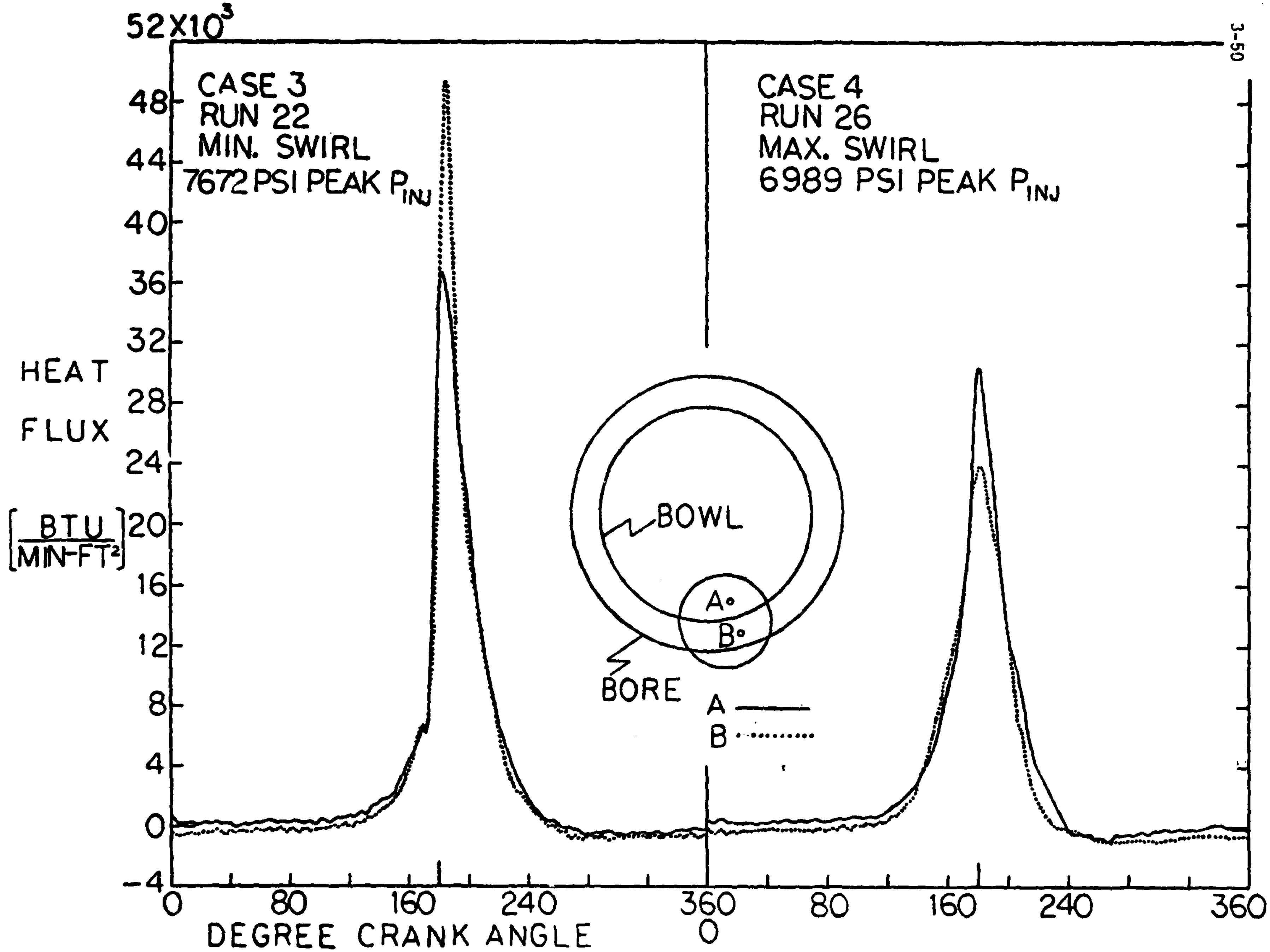
- MOTORING
  - MIN. SWIRL
    - 1000 RPM
    - 2000 RPM
  - MAX. SWIRL
    - 1000 RPM
    - 2000 RPM


52X10^3
POSITION A
CASE 1 ----
2 ——
3 -·-·-
4 ········
48
44
40
36
32
28
24
20
16
12
8
4
0
-4
HEAT FLUX BTU/MIN-FT²
0
80
160
240
360
DEGREE CRANK ANGLE
6-.0098-165 NOZZLE
2000 RPM
17°CA BTDC INJ. TIMING
0.5 EQUIVALENCE RATIO
1.5 ATM P INTAKE
CASE 1
MIN. SWIRL
4285 PSI PEAK P INJ
CASE 2
MAX. SWIRL
4328 PSI PEAK P INJ
CASE 3
MIN. SWIRL
7672 PSI PEAK P INJ
CASE 4
MAX. SWIRL
6989 PSI PEAK P INJ


52X10^3
POSITION B
CASE 1 ----
2 ——
3 -·-·-
4 ········
HEAT FLUX BTU/MIN-FT²
48
44
40
36
32
28
24
20
16
12
8
4
0
-4
0
80
160
240
360
DEGREE CRANK ANGLE
6-.0098-165 NOZZLE
2000 RPM
17°CA BTDC INJ. TIMING
0.5 EQUIVALENCE RATIO
1.5 ATM P INTAKE
CASE 1
MIN. SWIRL
4285 PSI PEAK P INJ
CASE 2
MAX. SWIRL
4328 PSI PEAK P INJ
CASE 3
MIN. SWIRL
7672 PSI PEAK P INJ
CASE 4
MAX. SWIRL
6989 PSI PEAK P INJ

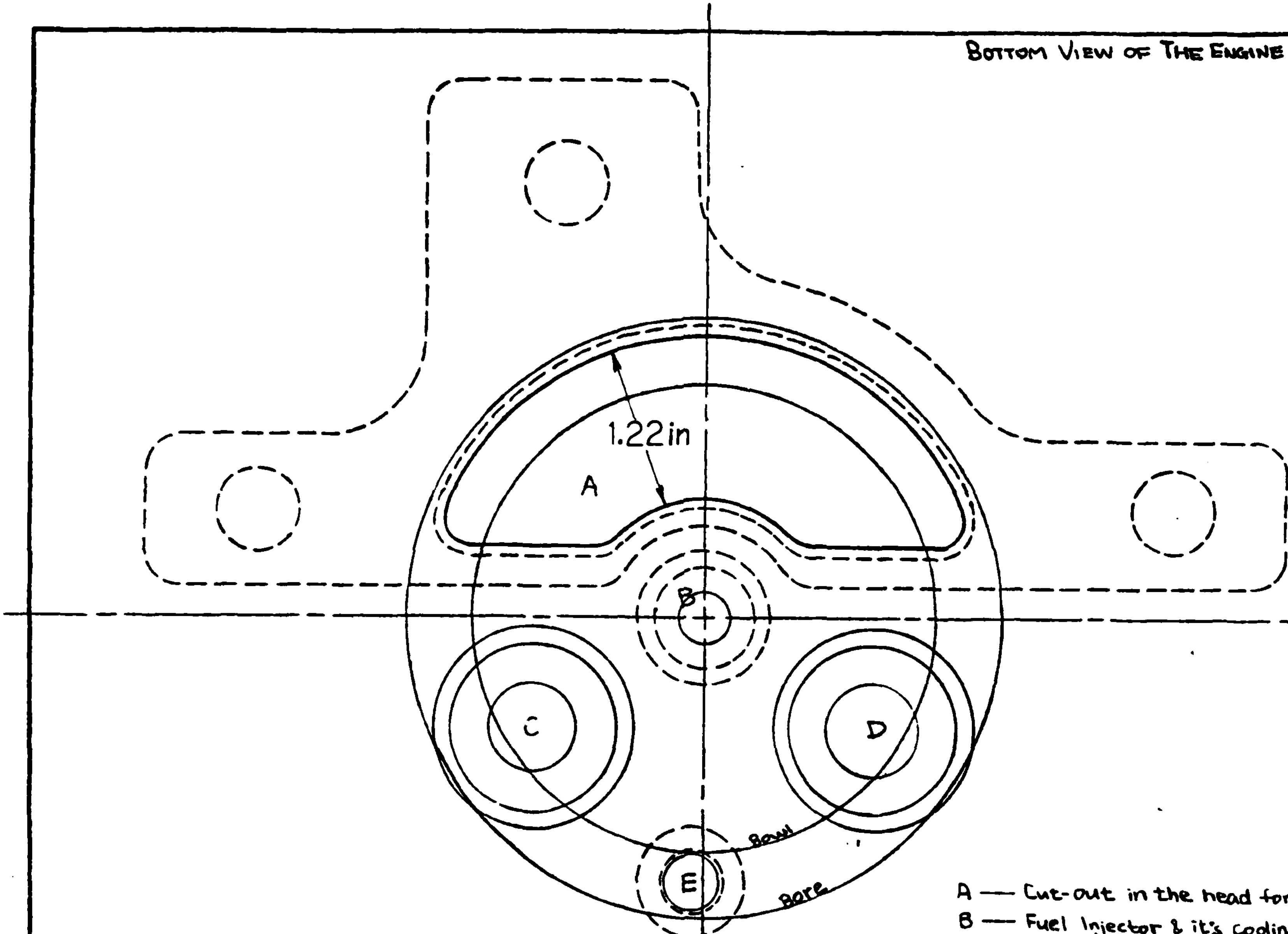

52 × 10^3
48
44
40
36
32
28
24
20
16
12
8
4
0
−4
HEAT FLUX
[BTU / MIN-FT²]
CASE 1
RUN 20
MIN. SWIRL
4285 PSI PEAK P_INJ
CASE 2
RUN 24
MAX. SWIRL
4328 PSI PEAK P_INJ
BOWL
BORE
A
B
0
80
160
240
360
0
80
160
240
DEGREE CRANK ANGLE

3-49

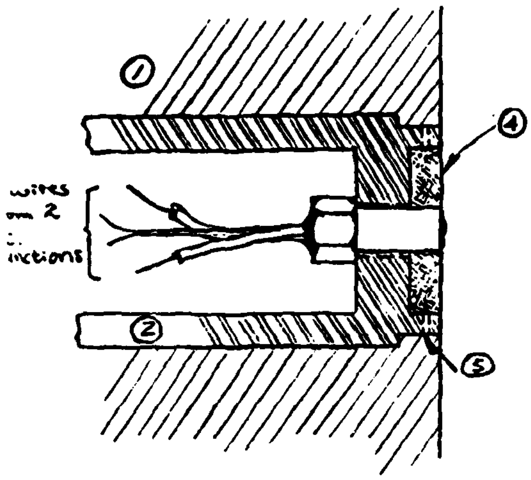


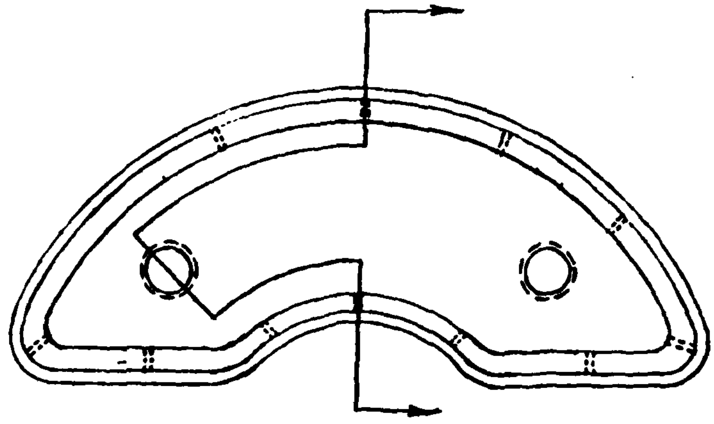
3-50
52X10³
HEAT FLUX [BTU / MIN-FT²]
48
44
40
36
32
28
24
20
16
12
8
4
0
-4
CASE 3
RUN 22
MIN. SWIRL
7672 PSI PEAK P_INJ
CASE 4
RUN 26
MAX. SWIRL
6989 PSI PEAK P_INJ
BOWL
BORE
A
B
0
80
160
240
360
0
80
160
240
360
DEGREE CRANK ANGLE

BOTTOM VIEW OF THE ENGINE HEAD



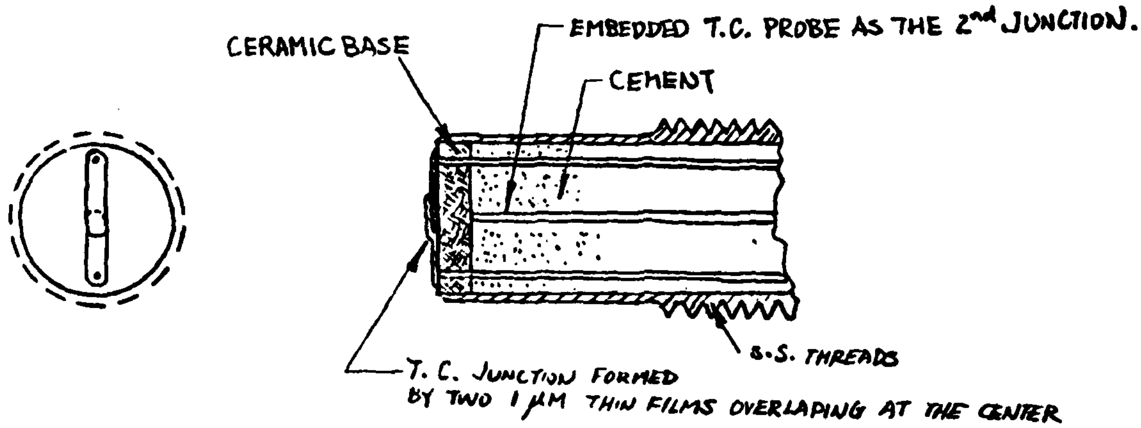
A — Cut-out in the head for the Plug.
B — Fuel Injector & it's cooling jacket.
C — Intake Valve.
D — Exhaust valve.
E — Pressure transducer.

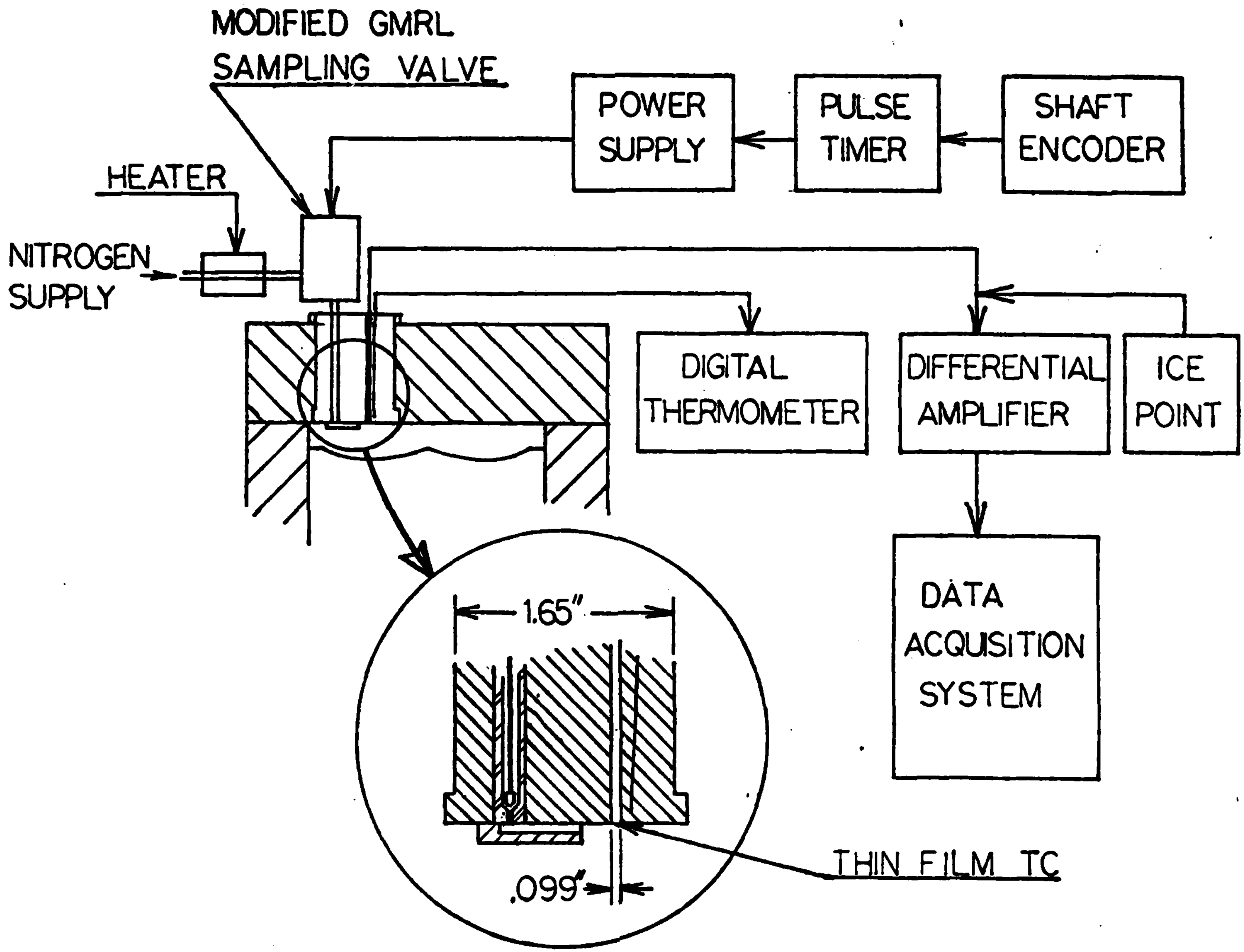




① ENGINE HEAD BLOCK.
② PLUG
③ HEAT FLUX TRANSDUCER (TWO-JUNCTION T.C. ON CERAMIC BASE)
④ CERAMIC PLATE.
⑤ SCREWS TO HOLD THE PLATE ON THE SIDE.

THE ENLARGED VIEW OF THE TIP OF PART ③ IS SHOWN BELOW:




MODIFIED GMRL
SAMPLING VALVE
HEATER
NITROGEN
SUPPLY
POWER
SUPPLY
PULSE
TIMER
SHAFT
ENCODER
DIGITAL
THERMOMETER
DIFFERENTIAL
AMPLIFIER
ICE
POINT
DATA
ACQUISITION
SYSTEM
1.65"
.099"
THIN FILM TC

Session 4
ARO COMBUSTION RESEARCH

Chairman: E. Mularz
U. S. Army Aviation Research and Development Command
U. S. Army Research and Technology Laboratory
Cleveland, OH

FLAME PROPAGATION IN SPRAYS

by

S.C. Yao, W.A. Sirignano, S.K. Aggarwal, and N. Ashgrizzadeh

Carnegie-Mellon University

Pittsburgh, PA 15213

A joint experimental - computational study is underway on flame propagation in sprays. The purpose is to identify the prominent physical, dynamical and chemical mechanisms involved in the burning of sprays and to develop a predictive capability via computation.

An experimental apparatus has been designed, fabricated, and tested which allows separate control of key parameters such as droplet size, fuel type, mixture ratio, distance between droplets, droplet velocity, and air velocity. This ability to vary independently several parameters allows a critical evaluation of any theoretical model.

A piezo-electric crystal is employed to pulse the volume in a fuel reservoir immediately behind a multi-orifice fuel injector plate. The orifice size, pulsing duration and amplitude, and time between pulses controls initial droplet size, spacing, and velocity. Air flow is carefully distributed across the spray by perforated tubes. A wedge-shaped flame is held by a thin flameholder so that locally the flame approximates a one-dimensional structure.

A one-dimensional model predicts that the flame is not perfectly steady. Some vaporization and mixing of fuel vapor with air occurs before the flame.

With sufficiently volatile fuels, a flammable mixture results for a deflagration to result which does not rely on further vaporization. The liquid fuel droplets entering the flame may or not complete vaporization before they leave the flame. Droplet burning has been seen to occur well beyond the flame-front. Since flame thickness can be smaller than average distance between droplets, an unsteady situation arises. The degree of unsteadiness would increase as the fuels become less volatile, the distance between droplets increases, and the droplets become larger.

In the future, experimental diagnostics and further theoretical modelling are intended to study this phenomenon more carefully.

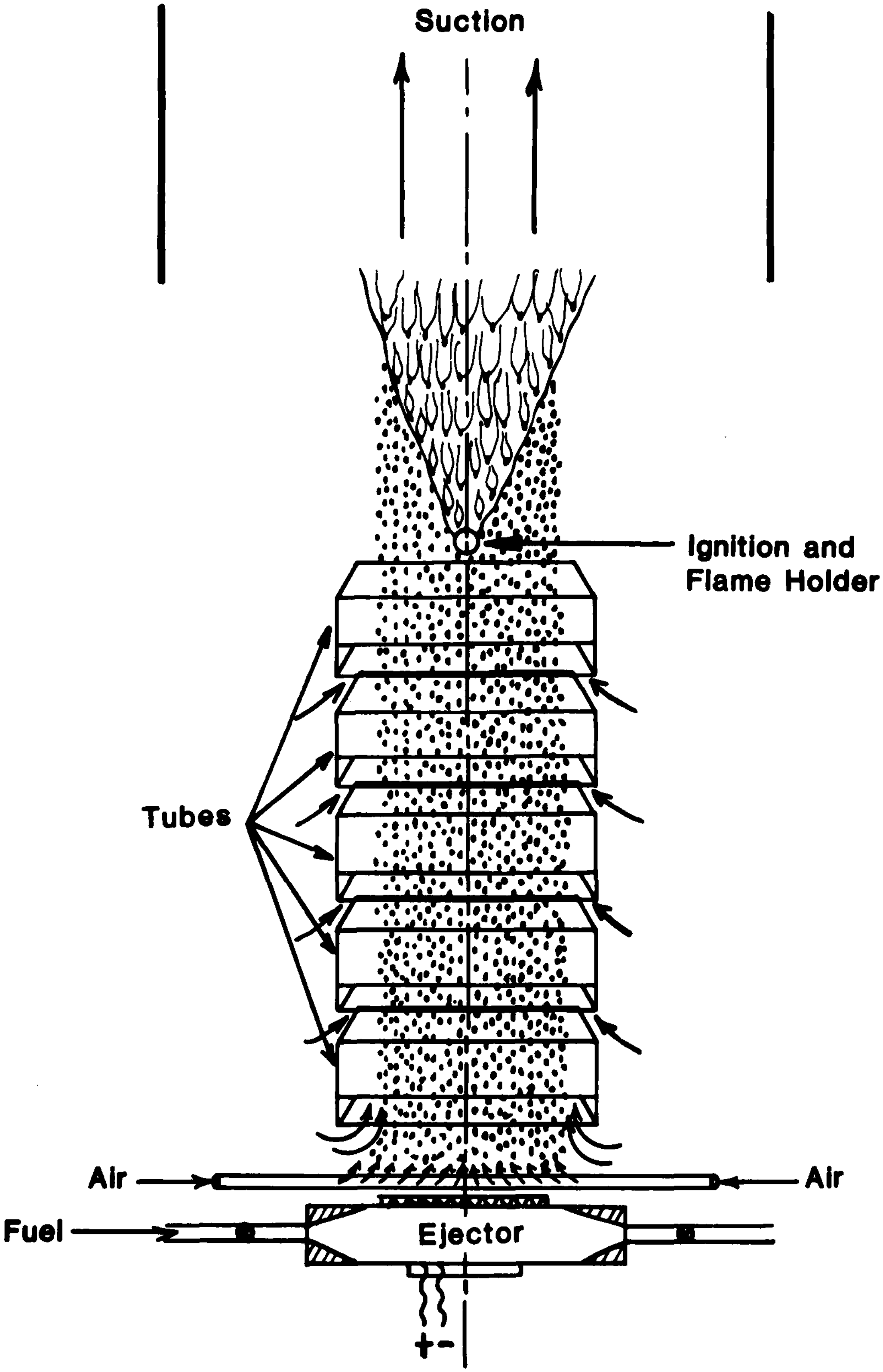


FIG. 1 Schematic of the Spray Generator

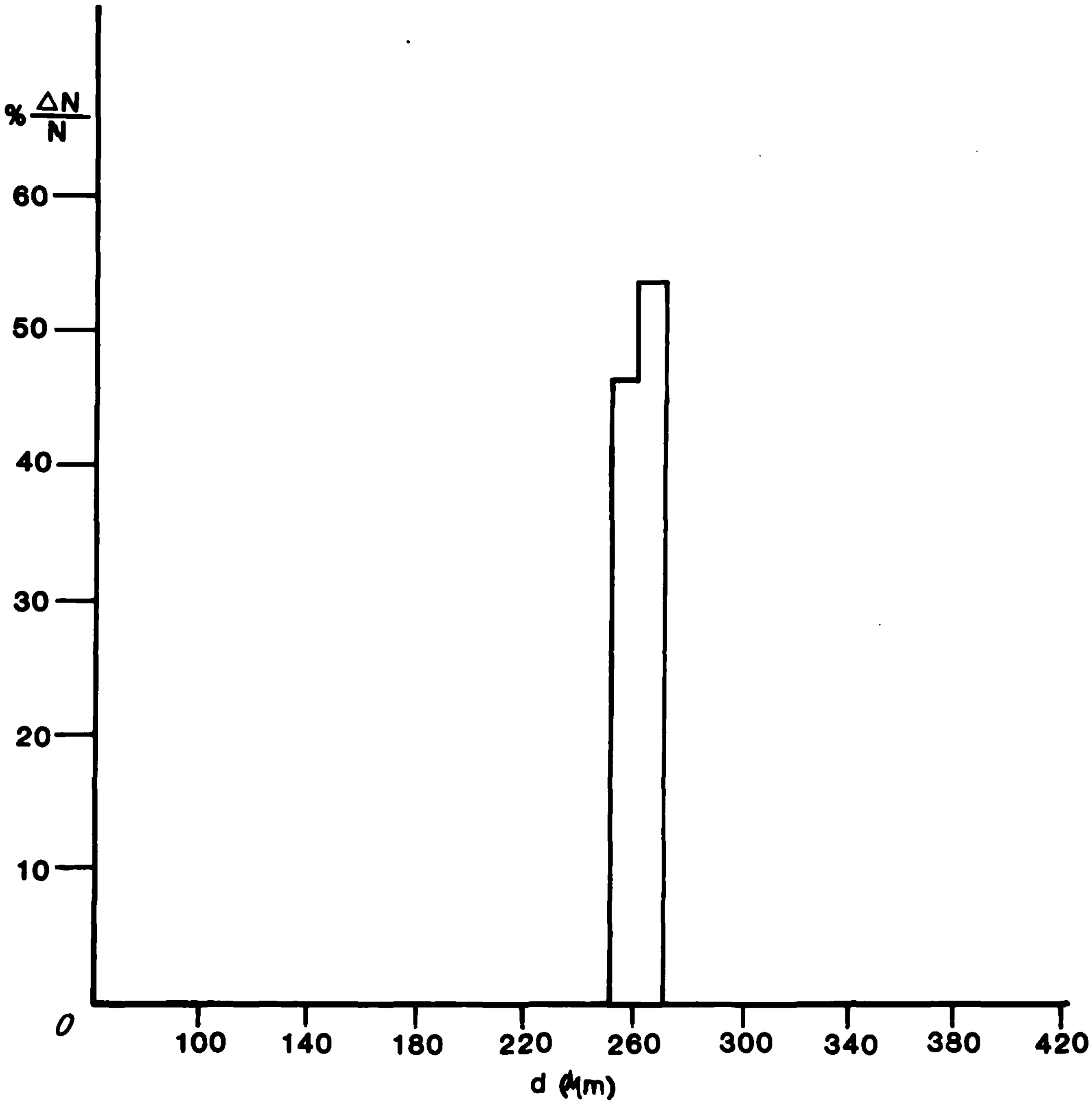
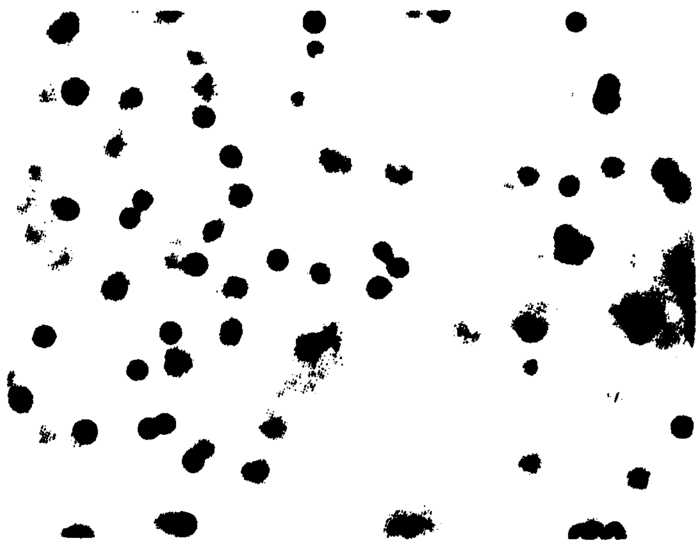


FIG.2 Generated Droplet Spectrum



(A) DISPERSED DROPLETS IN SPRAY

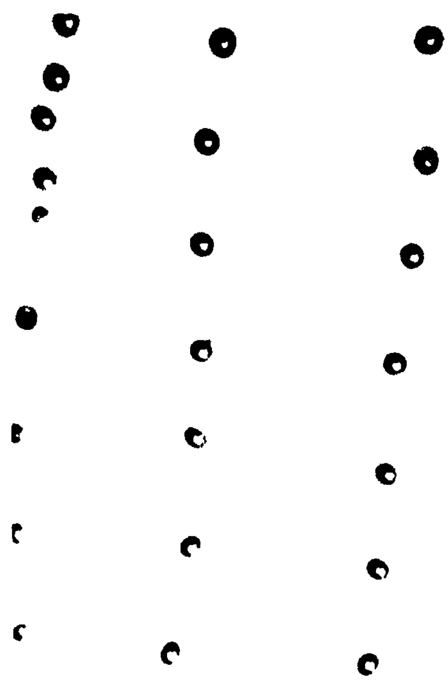


FIG. 3. (B) EJECTED DROPLETS NEAR THE GENERATOR PLATE

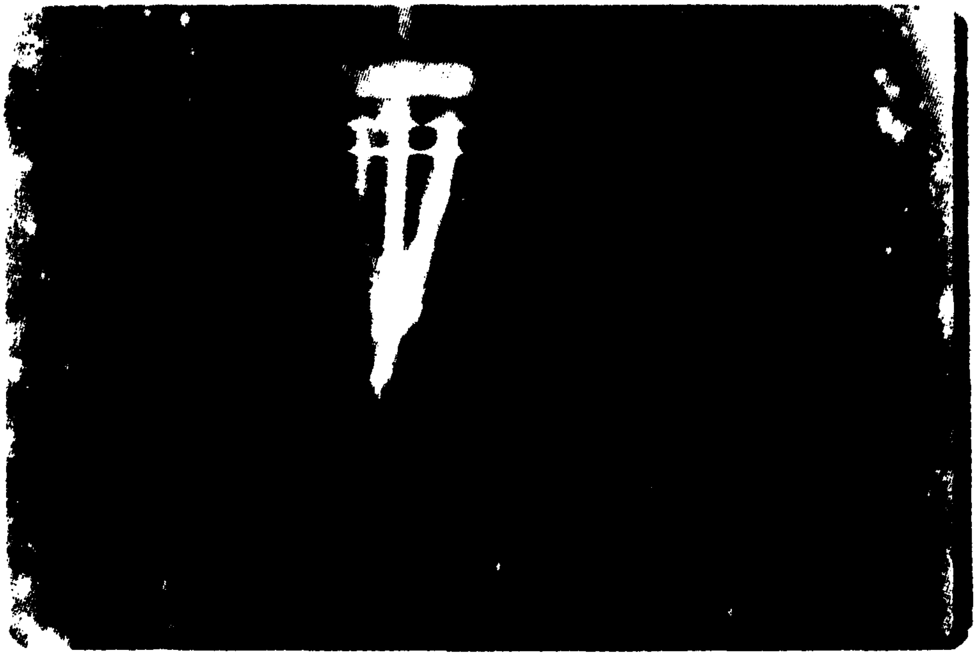
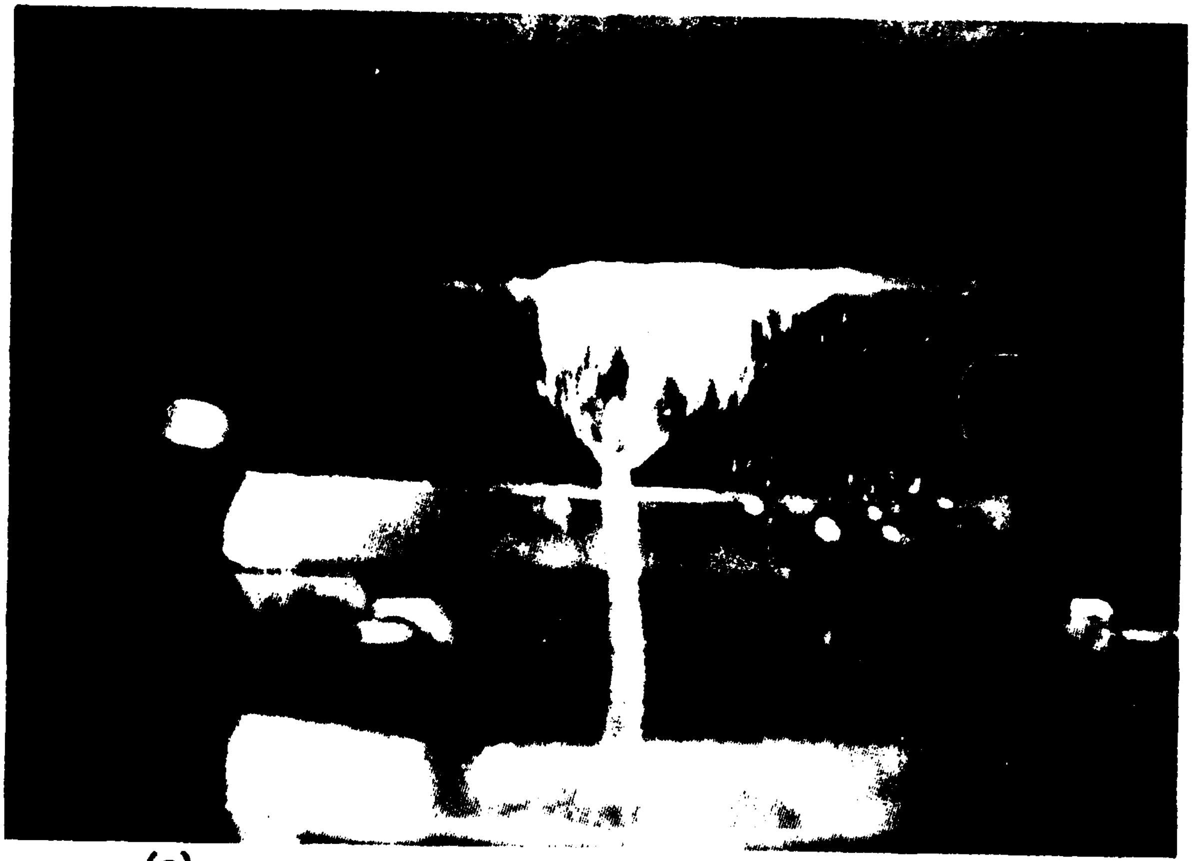


FIG.4 Blue Flame of Hexane Spray (150μm)



(a)

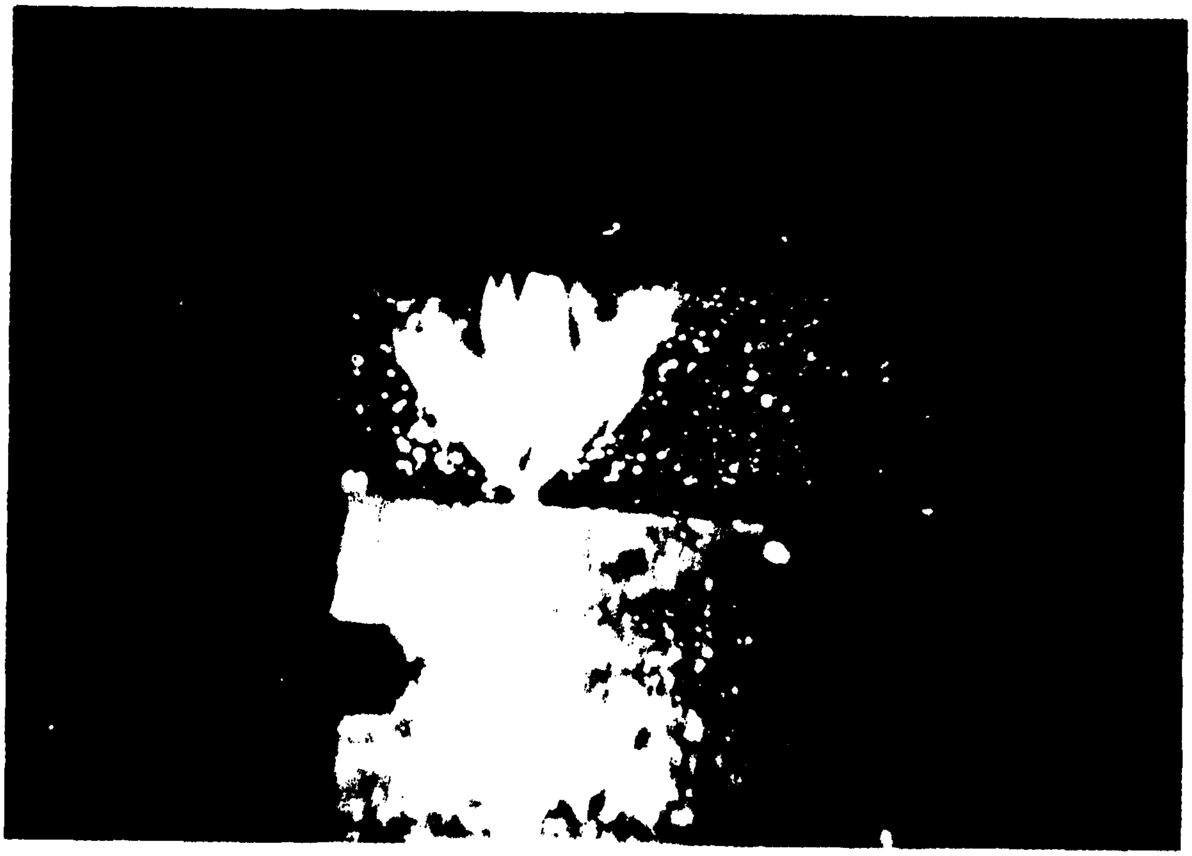


FIG.5 (b) Flame of the Hexane Spray (300μm droplet dia.)

FIG.6 Flame of the Toluene Spray (300μm dia.)

Computational Results

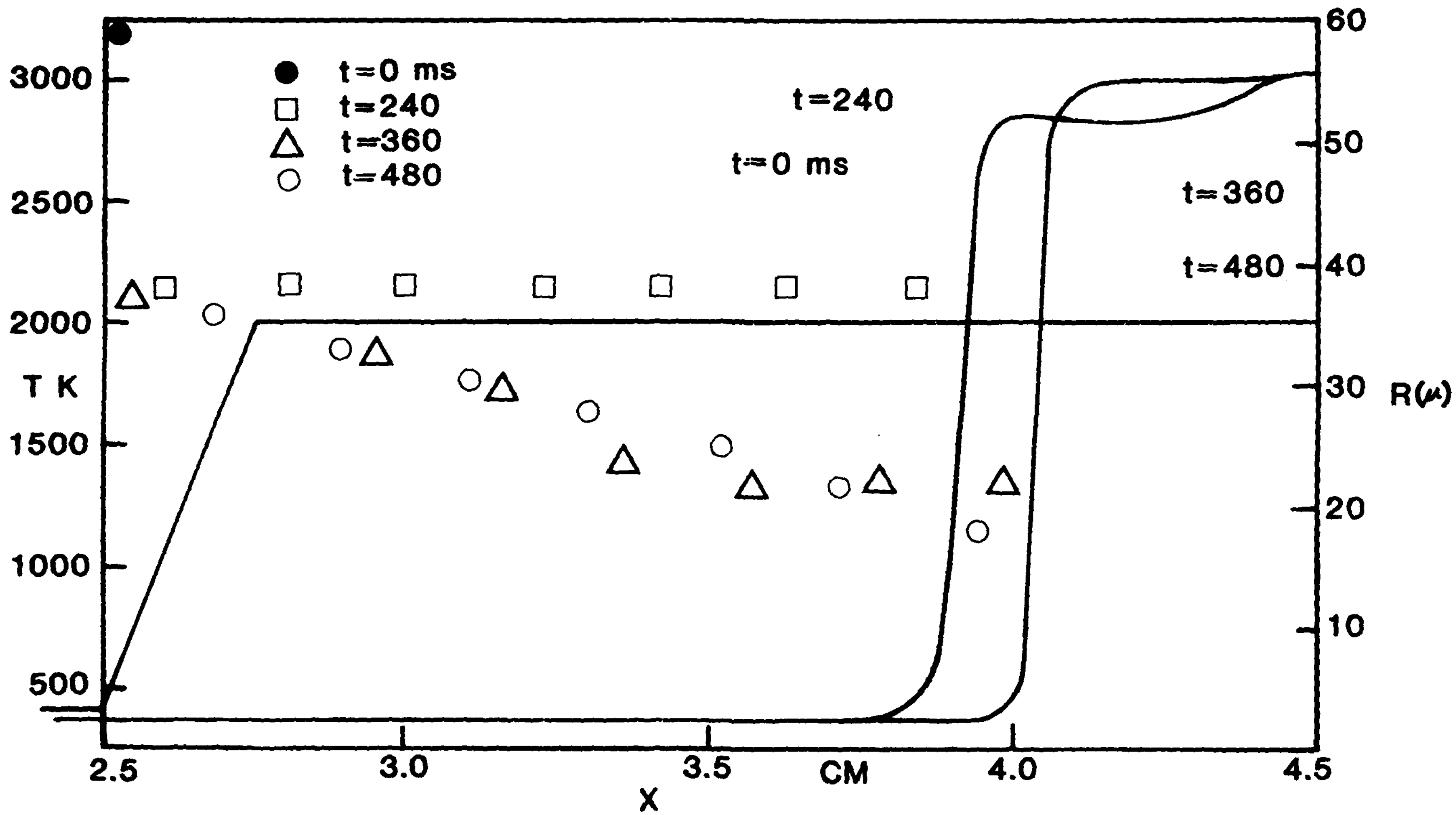
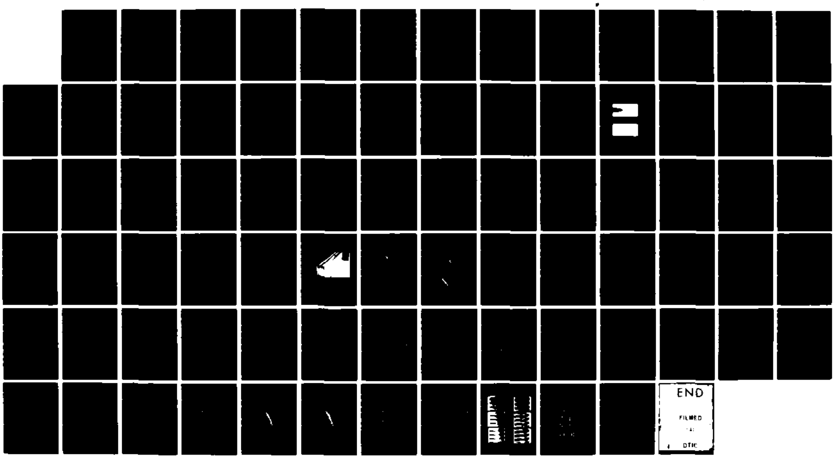
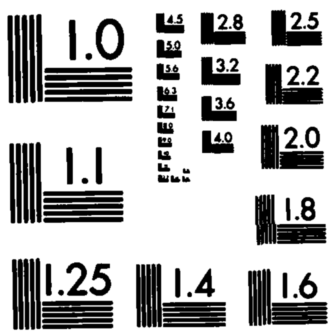


FIG. 7 (a) Gas Temperature Profiles at different times
(b) Droplet Radius vs X at different times

AD-A122 843 ENGINES/FUELS WORKSHOP 6-8 DECEMBER 1982 SAN ANTONIO TEXAS(U) SOUTHWEST RESEARCH INST SAN ANTONIO TX ARMY FUELS AND LUBRICANTS RESEARCH LAB D M MANN ET AL. 1982 3/3

UNCLASSIFIED AFLRL-164 DAAK70-82-C-0001 F/G 21/4 NL





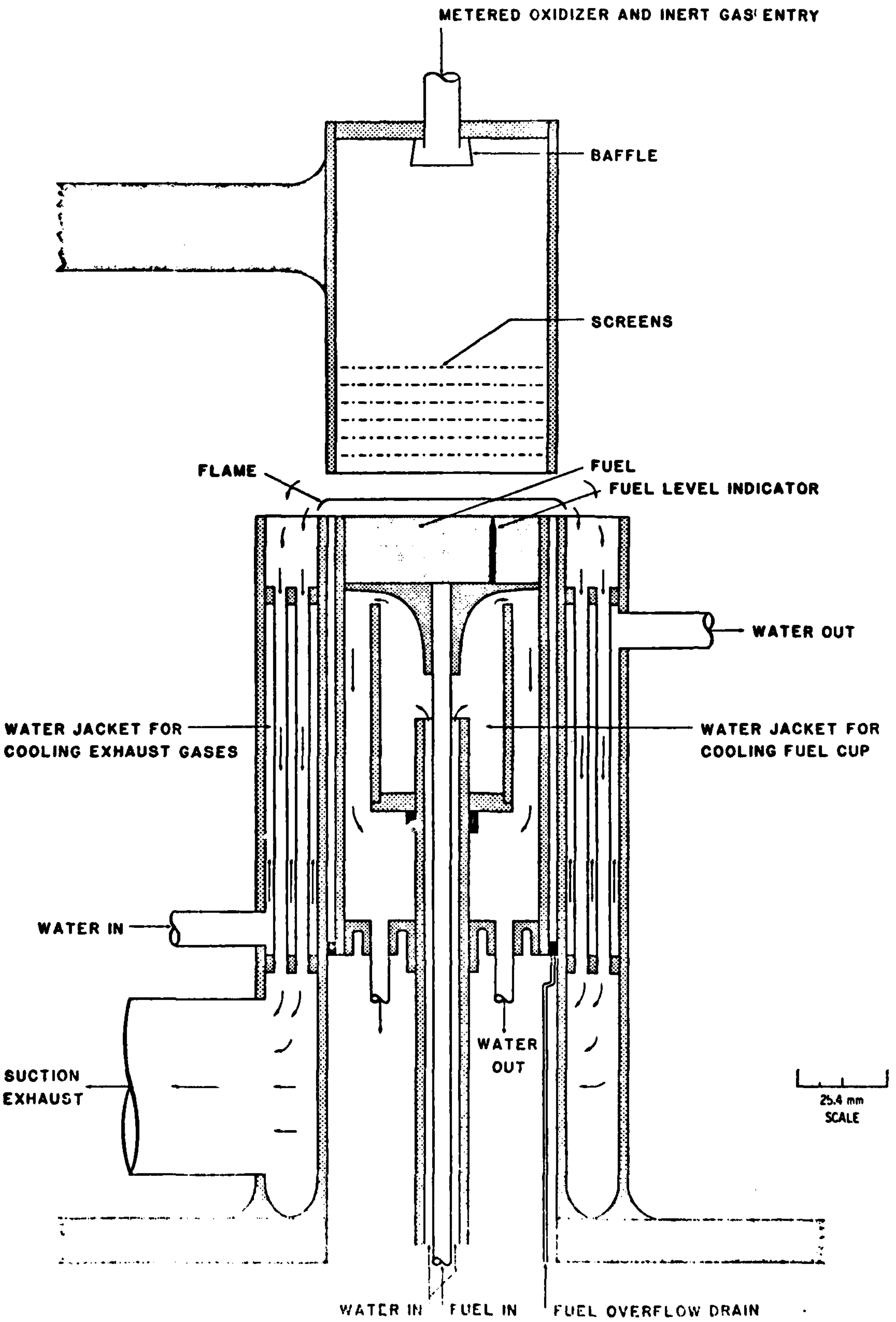
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

MECHANISMS OF COMBUSTION OF HYDROCARBON/ACOHOL FUEL BLENDS

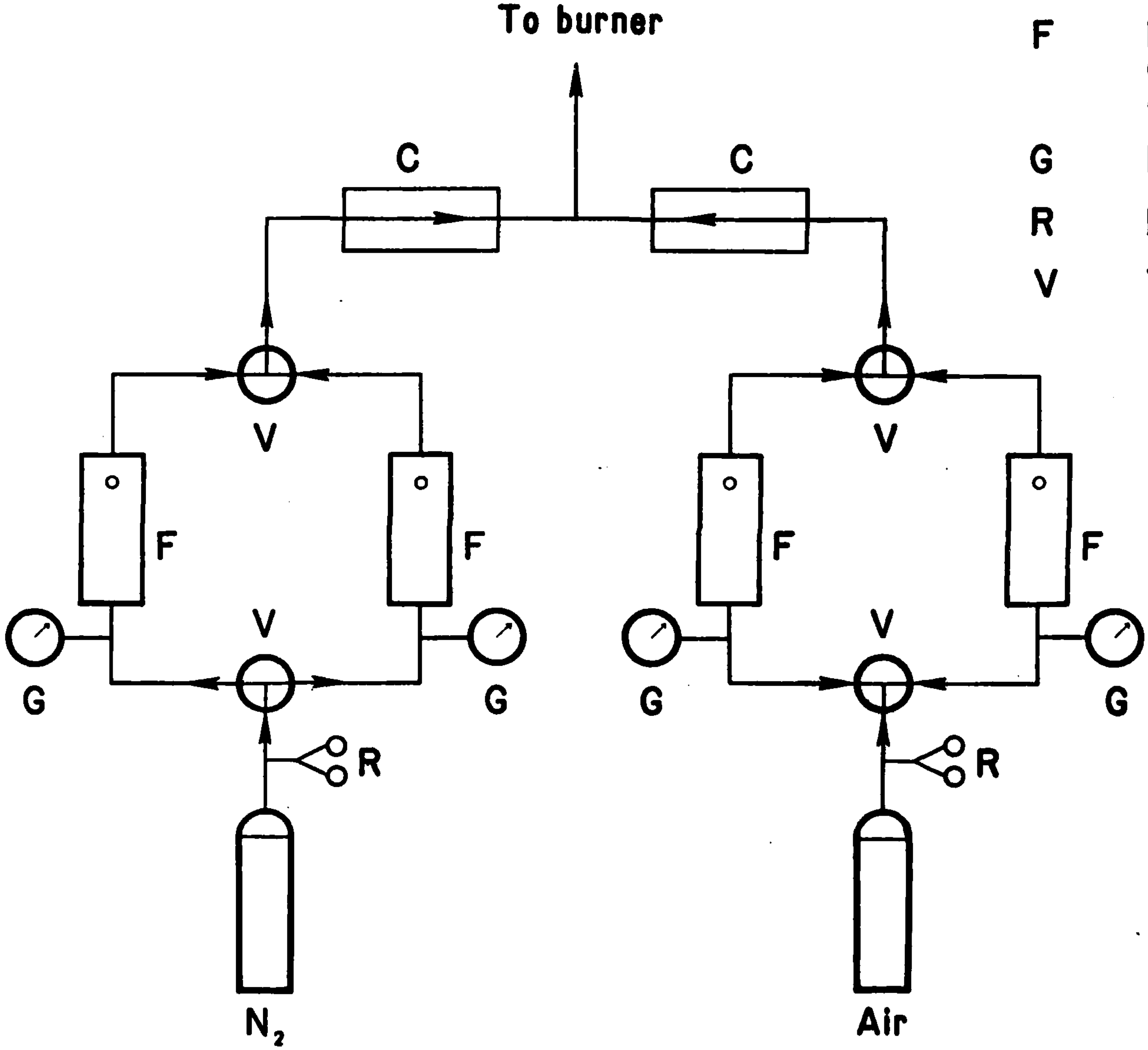
K. Seshadri

ABSTRACT

An experimental and theoretical study concerning the mechanisms of combustion of alternate fuels has been initiated. The fuels to be considered are homogeneous solutions of alcohols in liquid hydrocarbon fuels. A thin, steady, laminar diffusion-flame in a counterflow configuration will be established in the laboratory above pools of heptane/toluene/methanol, heptane/toluene/ethanol, heptane/toluene, heptane, toluene, methanol and ethanol. The ratios of the concentration of heptane and toluene in the solutions will be chosen to approximate the ratios of aliphatics to aromatics in commercial fuels (e.g. gasoline, diesel and shale oil). Concentration profiles for stable species in the gas phase above the burning fuel surface will be measured by use of gas sampling and gas chromatographic analysis. Temperature profiles in the gas phase and in the fuel will be measured by use of thermocouples. Critical conditions of flame extinction will also be measured. Theoretical analysis will be based on an asymptotic theory in the limit of a large ratio of the activation energy to the thermal energy in the flame. The mechanisms of combustion of fuel blends will be compared with its components. Results to be obtained include (1) quantitative comparisons of the relative reactivities of the fuels, (2) quantitative values for the overall activation energies and the overall preexponential factors for the gas phase oxidation of the fuels and (4) chemical kinetic mechanisms for fuel pyrolysis. We anticipate that this study will aid development of alternate fuels obtained from nonpetroleum sources for use in automotive engines.

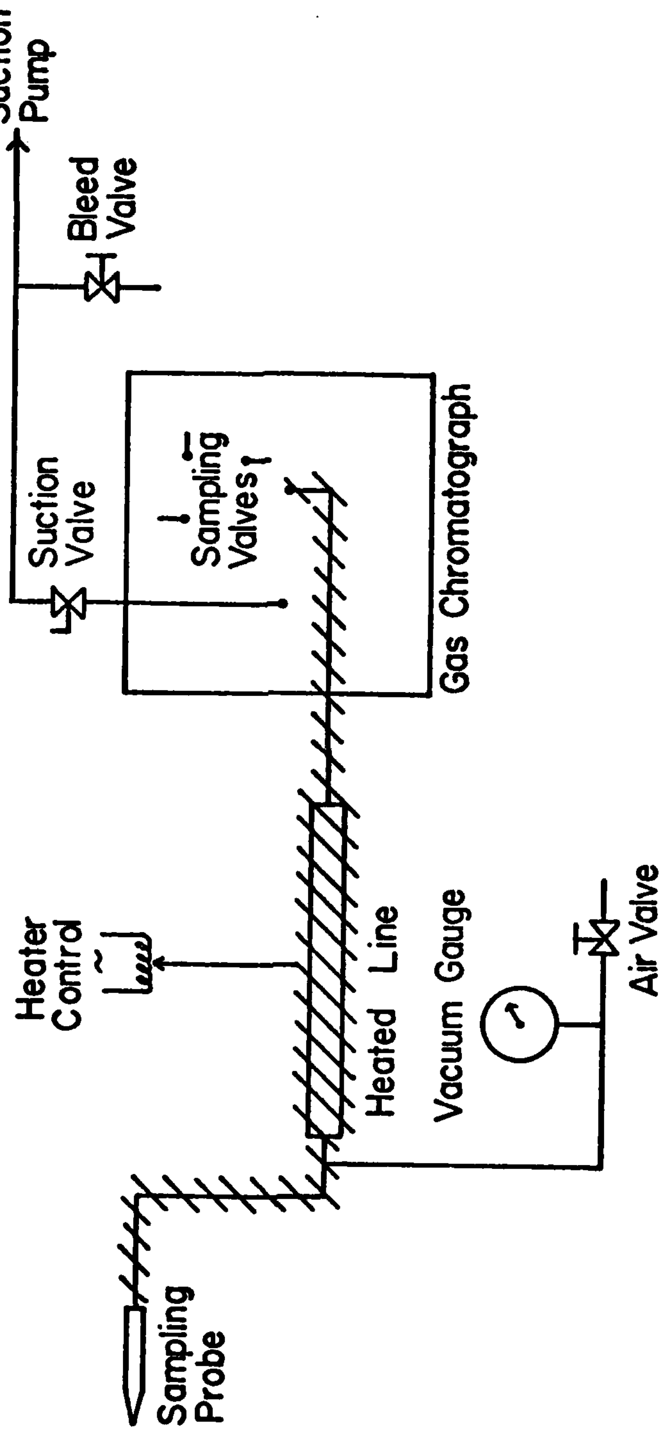


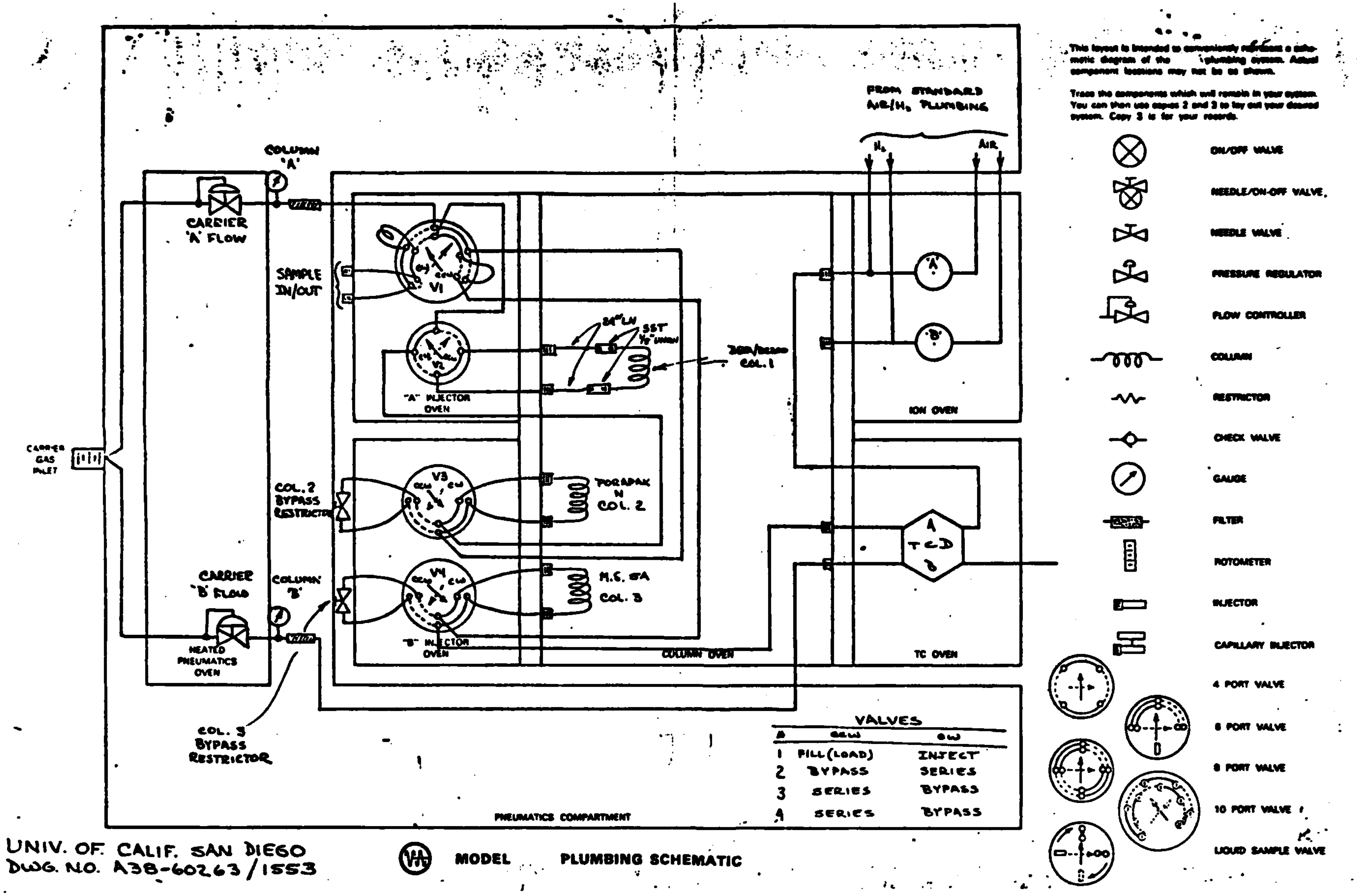
METERED OXIDIZER AND INERT GAS ENTRY
BAFFLE
SCREENS
FLAME
FUEL
FUEL LEVEL INDICATOR
WATER OUT
WATER JACKET FOR COOLING EXHAUST GASES
WATER JACKET FOR COOLING FUEL CUP
WATER IN
WATER OUT
SUCTION EXHAUST
25.4 mm SCALE
WATER IN
FUEL IN
FUEL OVERFLOW DRAIN



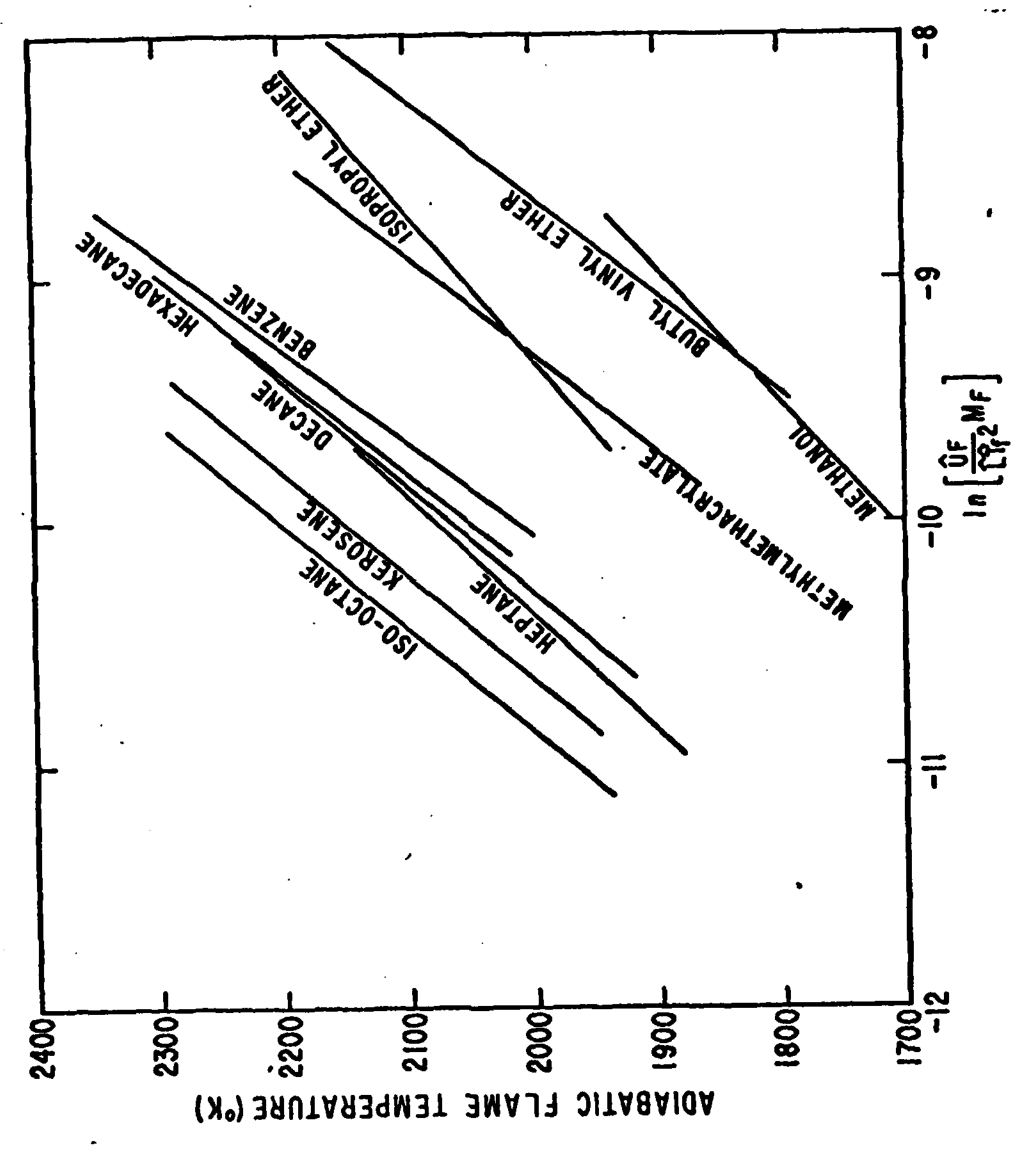
C	Check valve
F	Flowmeter with control valve at outlet
G	Pressure gauge
R	Regulator
V	Three way valve

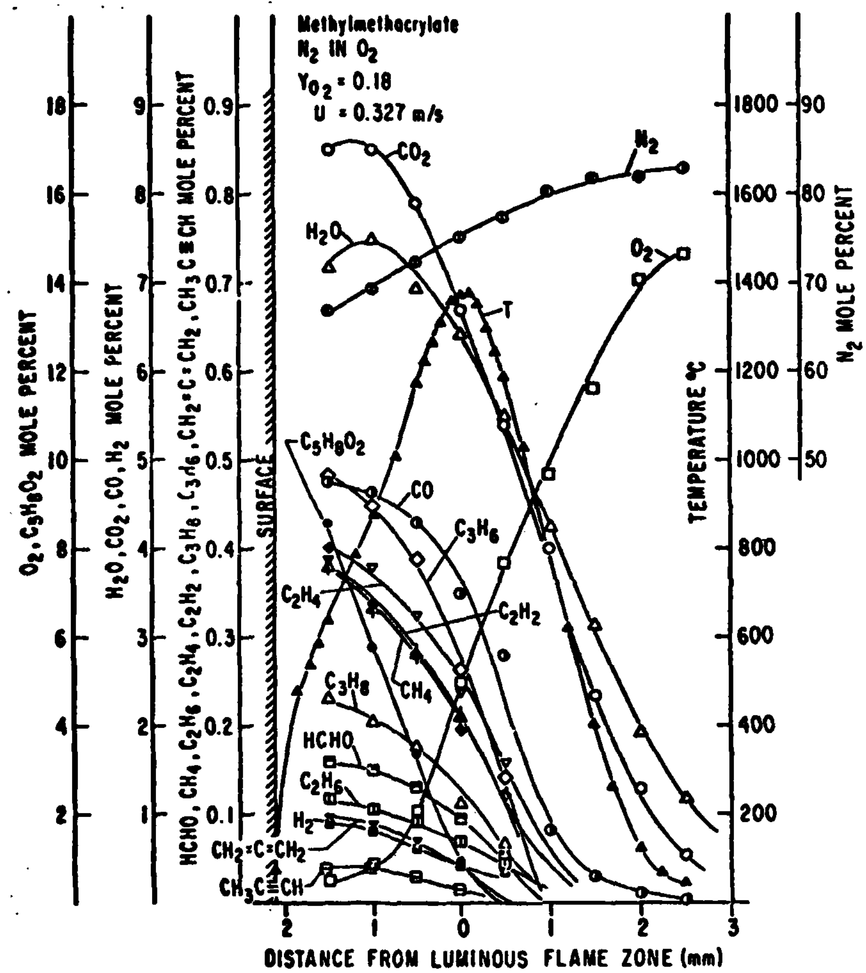
Schematic illustration of the gas handling system.


Suction Pump
Bleed Valve
Suction Valve
Sampling Valves
Gas Chromatograph
Heater Control
Heated Line
Vacuum Gauge
Air Valve
Sampling Probe



This layout is intended to conveniently represent a schematic diagram of the plumbing system. Actual component locations may not be as shown.
Trace the components which will remain in your system. You can then use copies 2 and 3 to lay out your desired system. Copy 3 is for your records.
ON/OFF VALVE
NEEDLE/ON-OFF VALVE
NEEDLE VALVE
PRESSURE REGULATOR
FLOW CONTROLLER
COLUMN
RESTRICTOR
CHECK VALVE
GAUGE
FILTER
ROTOMETER
INJECTOR
CAPILLARY INJECTOR
4 PORT VALVE
6 PORT VALVE
8 PORT VALVE
10 PORT VALVE
LIQUID SAMPLE VALVE
FROM STANDARD AIR/H2 PLUMBING
H2
AIR
COLUMN 'A'
CARRIER 'A' FLOW
SAMPLE IN/OUT
V1
V2
"A" INJECTOR OVEN
24" LN
SST 1/8" UNION
COL. 1
'A'
'B'
ION OVEN
CARRIER GAS INLET
COL. 2 BYPASS RESTRICTOR
V3
PORAPAK N COL. 2
TCD
CARRIER 'B' FLOW
COLUMN 'B'
V4
M.S. 5A COL. 3
HEATED PNEUMATICS OVEN
"B" INJECTOR OVEN
COLUMN OVEN
TC OVEN
COL. 3 BYPASS RESTRICTOR
VALVES
CCW CW
1 FILL (LOAD) INJECT
2 BYPASS SERIES
3 SERIES BYPASS
4 SERIES BYPASS
PNEUMATICS COMPARTMENT
UNIV. OF CALIF. SAN DIEGO
DWG. NO. A38-60263/1553
MODEL
PLUMBING SCHEMATIC

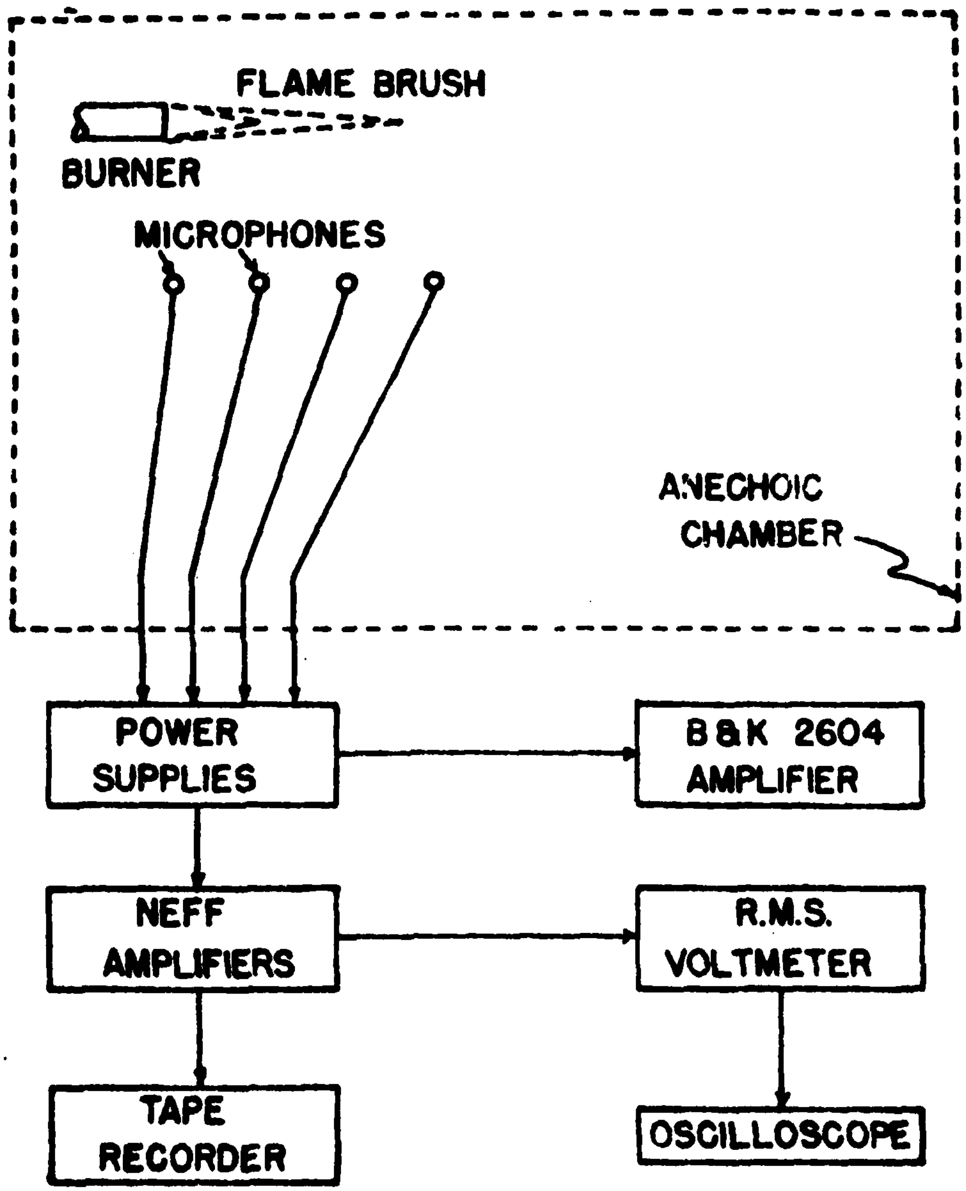

ADIABATIC FLAME TEMPERATURE (°K)
2400
2300
2200
2100
2000
1900
1800
1700
-12
-11
-10
-9
-8
$\ln\left[\frac{\dot{U}_F}{[T_f]^2}M_F\right]$
ISO-OCTANE
KEROSENE
HEPTANE
DECANE
HEXADECANE
BENZENE
ISOPROPYL ETHER
BUTYL VINYL ETHER
METHANOL
METHYLMETHACRYLATE


Methylmethacrylate
N_2 IN O_2
Y_{O_2} = 0.18
U = 0.327 m/s
O_2, $C_5H_8O_2$ MOLE PERCENT
H_2O, CO_2, CO, H_2 MOLE PERCENT
HCHO, CH_4, C_2H_6, C_2H_4, C_2H_2, C_3H_8, C_3H_6, CH_2=C=CH_2, $CH_3C\equiv CH$ MOLE PERCENT
SURFACE
TEMPERATURE °C
N_2 MOLE PERCENT
CO_2
H_2O
N_2
O_2
T
$C_5H_8O_2$
CO
C_3H_6
C_2H_4
C_2H_2
CH_4
C_3H_8
HCHO
C_2H_6
H_2
CH_2=C=CH_2
$CH_3C\equiv CH$
DISTANCE FROM LUMINOUS FLAME ZONE (mm)

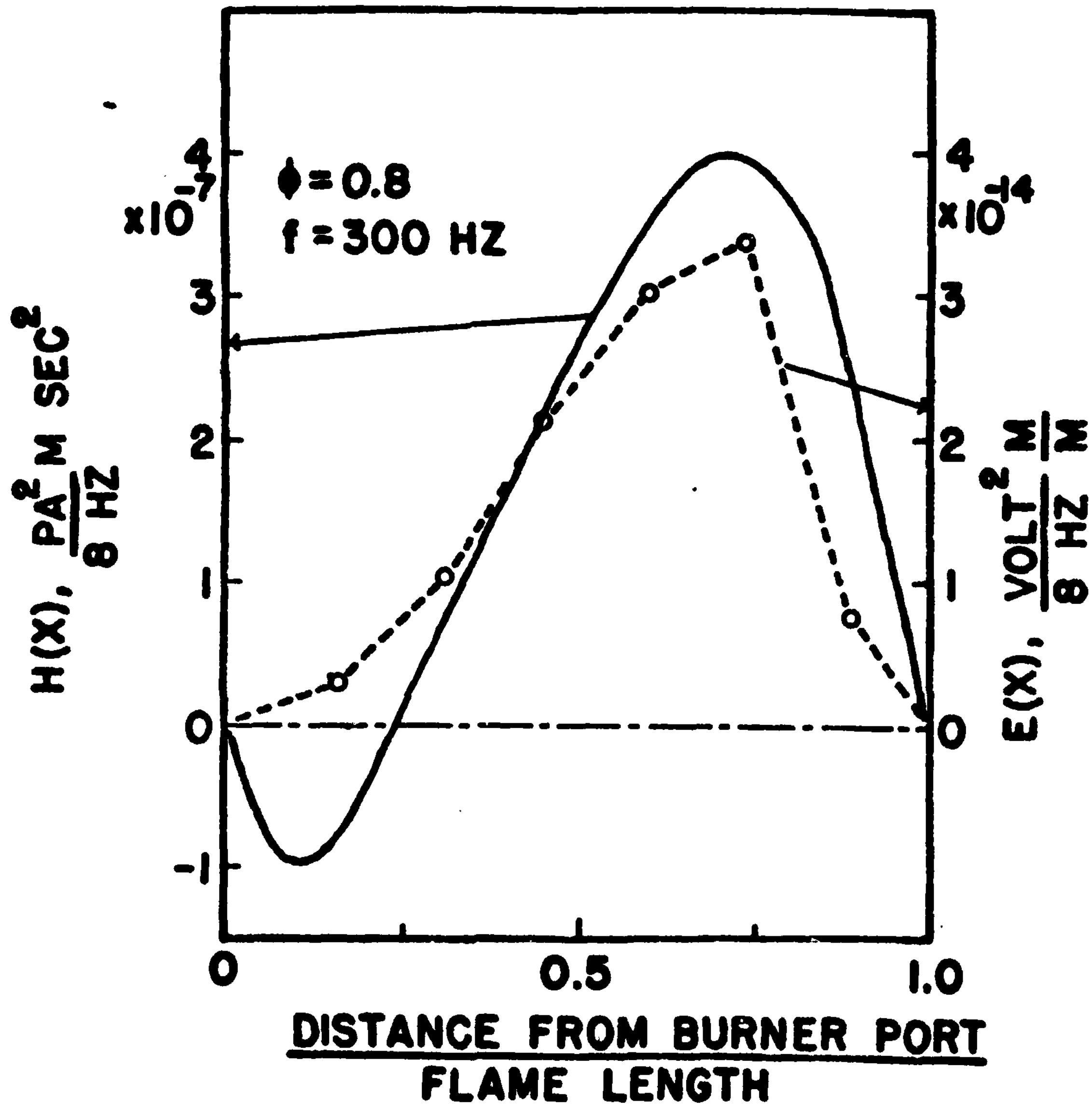
Acoustic Signature from Flames as a Combustion Diagnostic Tool

Warren C. Strahle
School of Aerospace Engineering
Georgia Institute of Technology
Atlanta, GA 30332

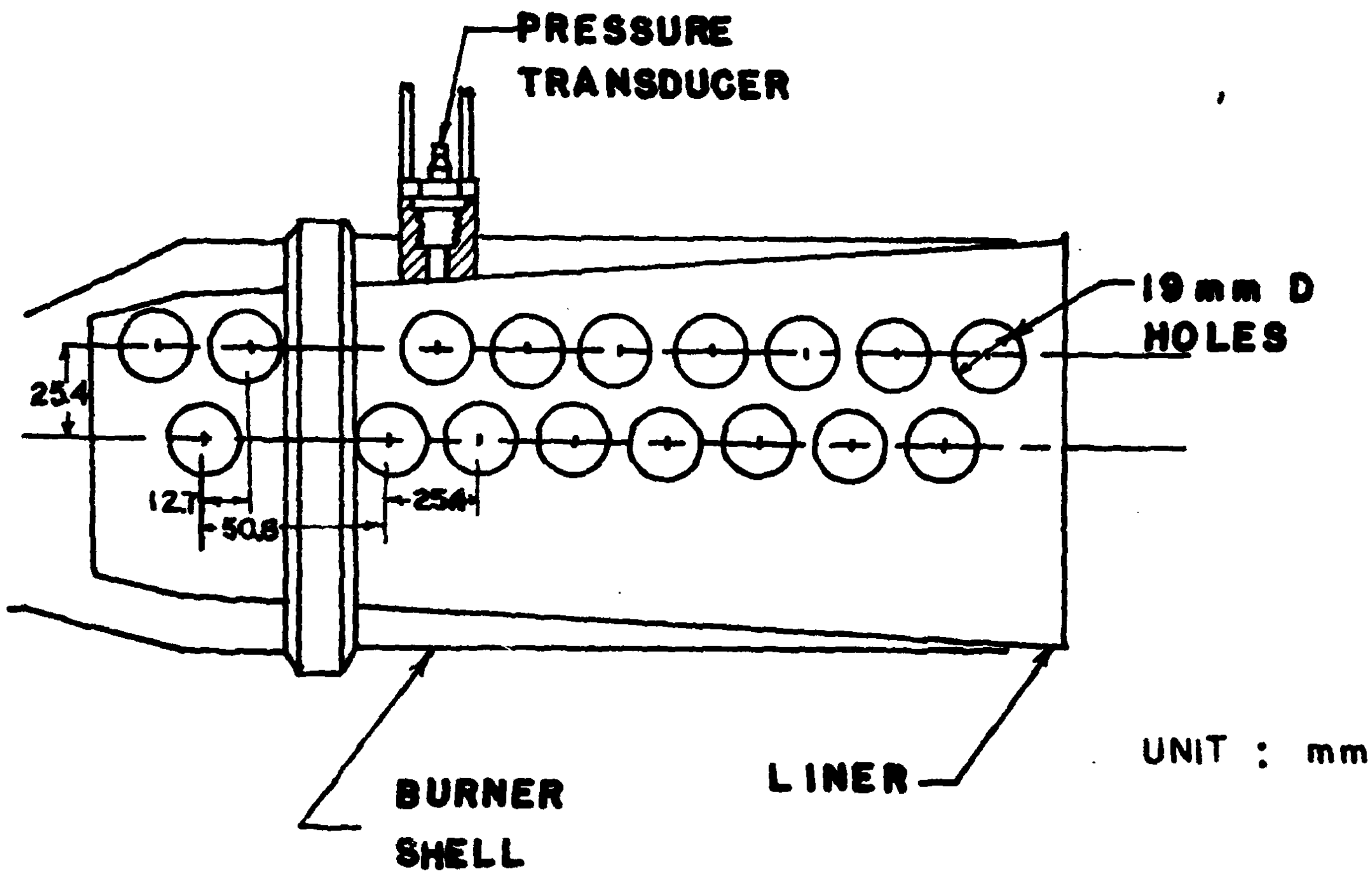
Experiments and analysis are described on the problem of using combustion noise output as a non-intrusive diagnostic of the combustion process in gas turbine combustors. The acoustic noise output is analytically linked to the heat release rate fluctuation distribution in the combustor; consequently, appropriate listening to the noise can yield the heat release rate distribution. The experiments use multiple microphones and cross spectral densities between microphone pairs as the imput to the theory to extract heat release rate. Verification is performed by ion density measurements in the combustor. Speed of sound distribution, which is needed in the theory, is also measured by an acoustic technique. Prior work on an open jet flame is also discussed.

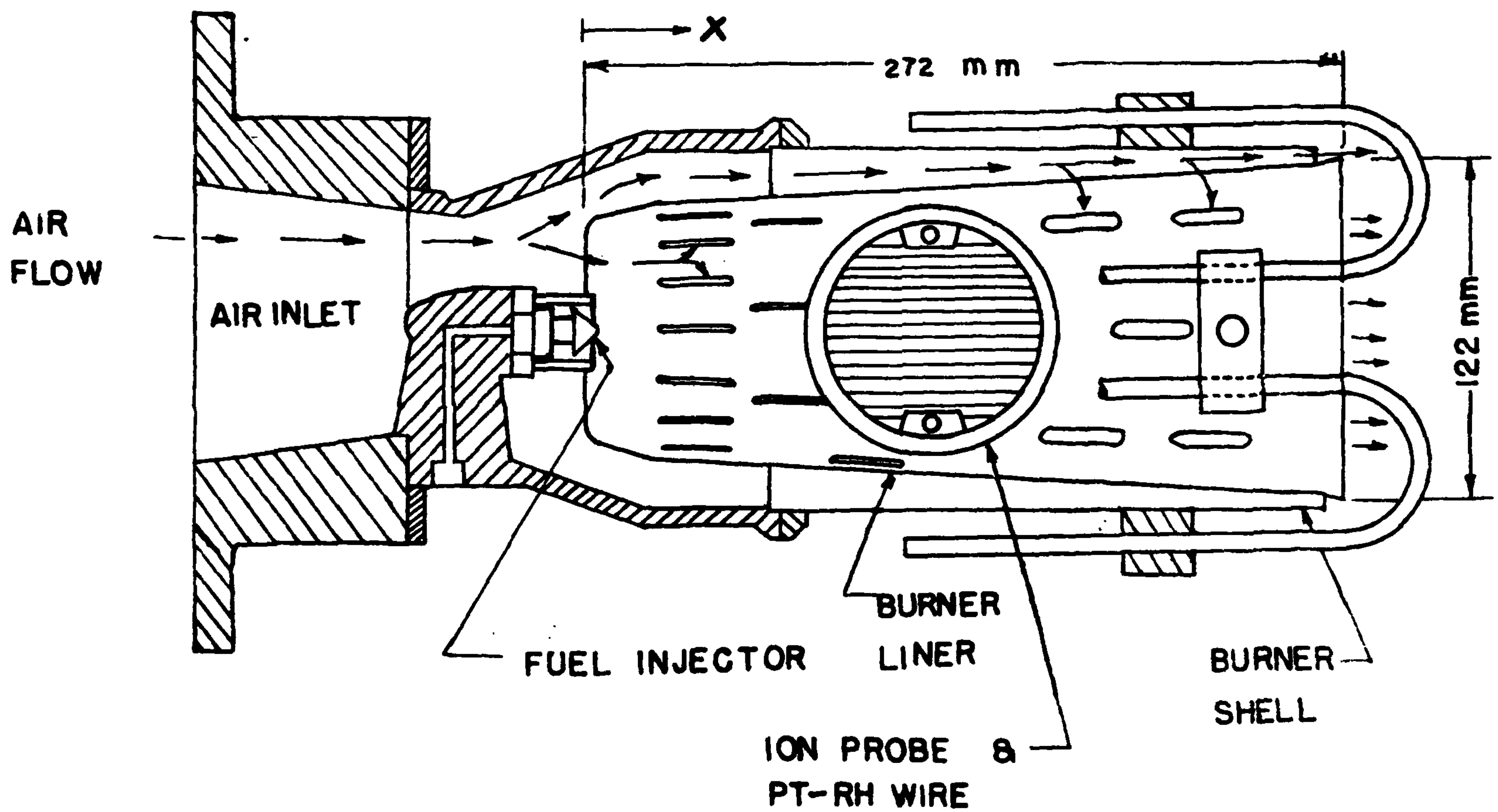


Data acquisition schematic
for acoustic measurements.

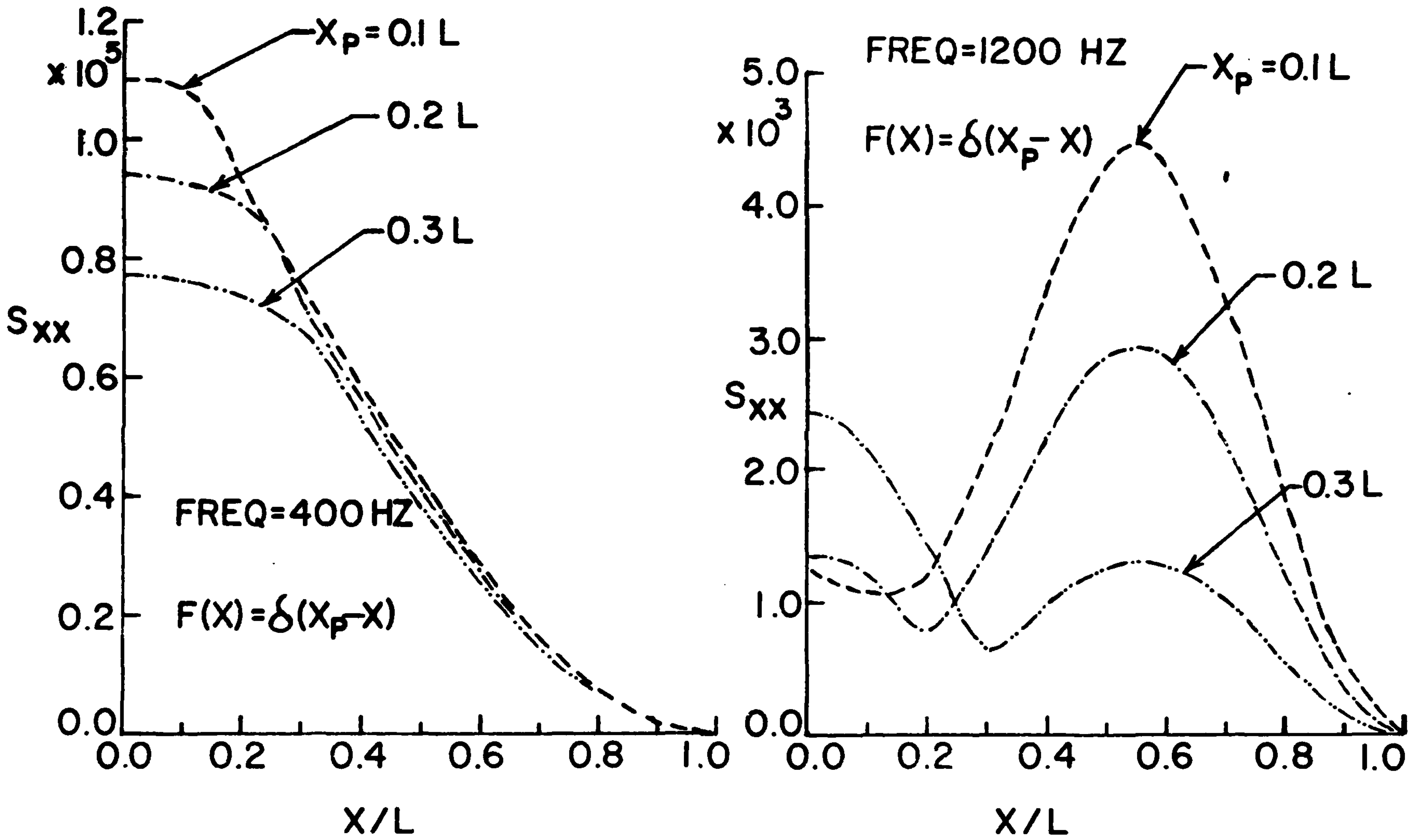


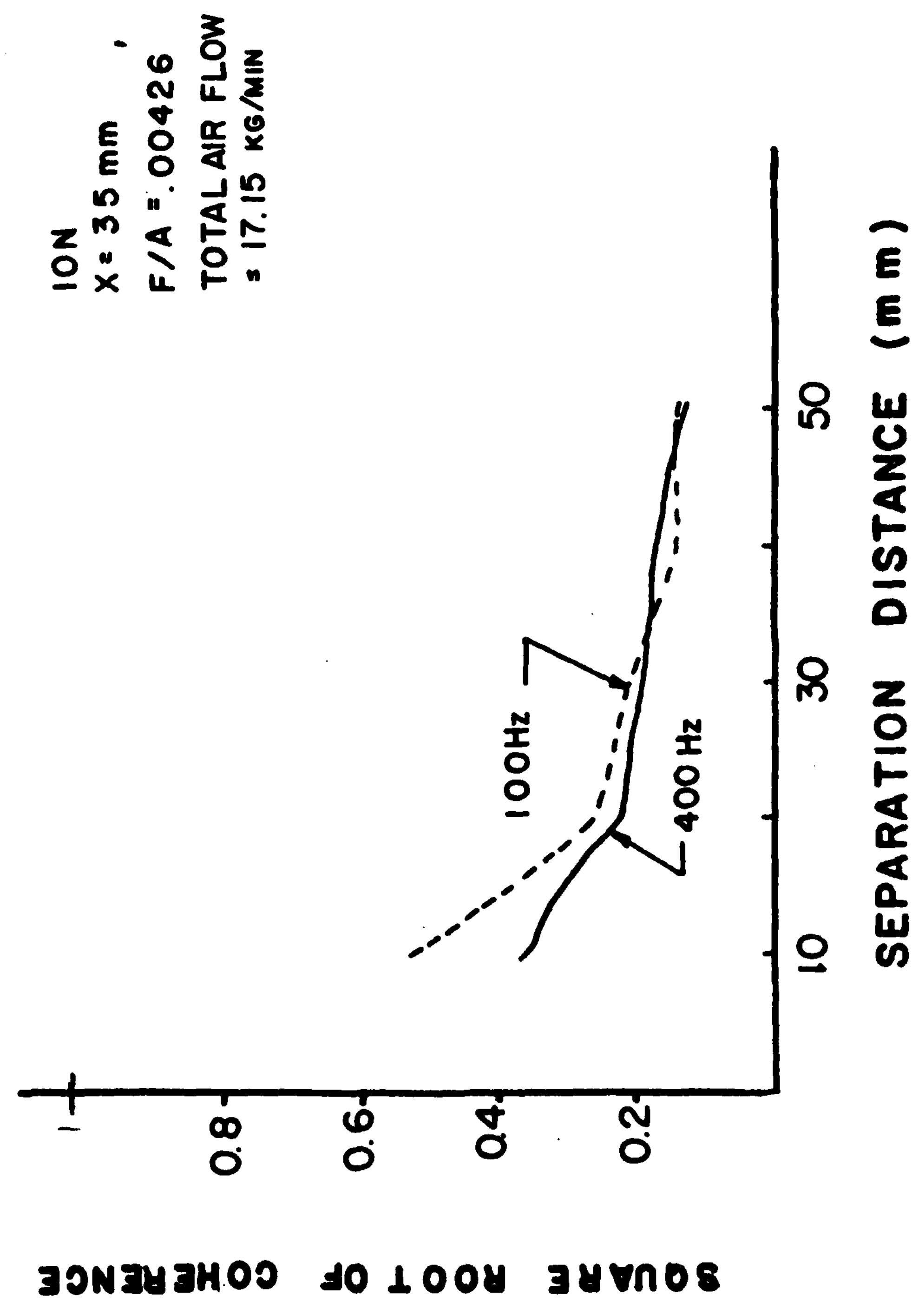
Heat release fluctuation function and light emission function vs. length along flame axis for the $\phi = 0.8$ flame at 300 Hz.


PRESSURE
TRANSDUCER
19 mm D
HOLES
25.4
12.7
50.8
25.4
BURNER
SHELL
LINER
UNIT : mm

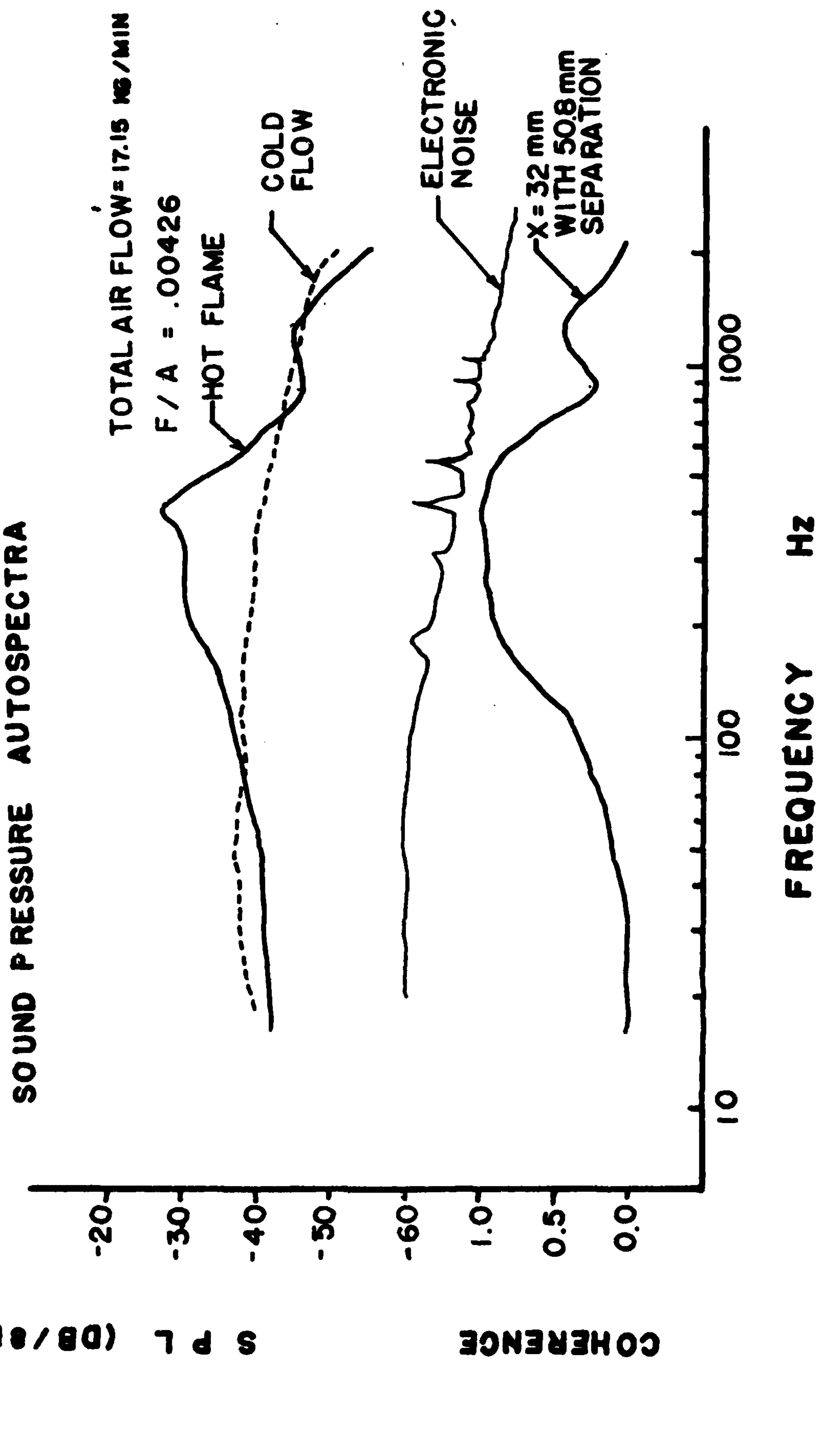


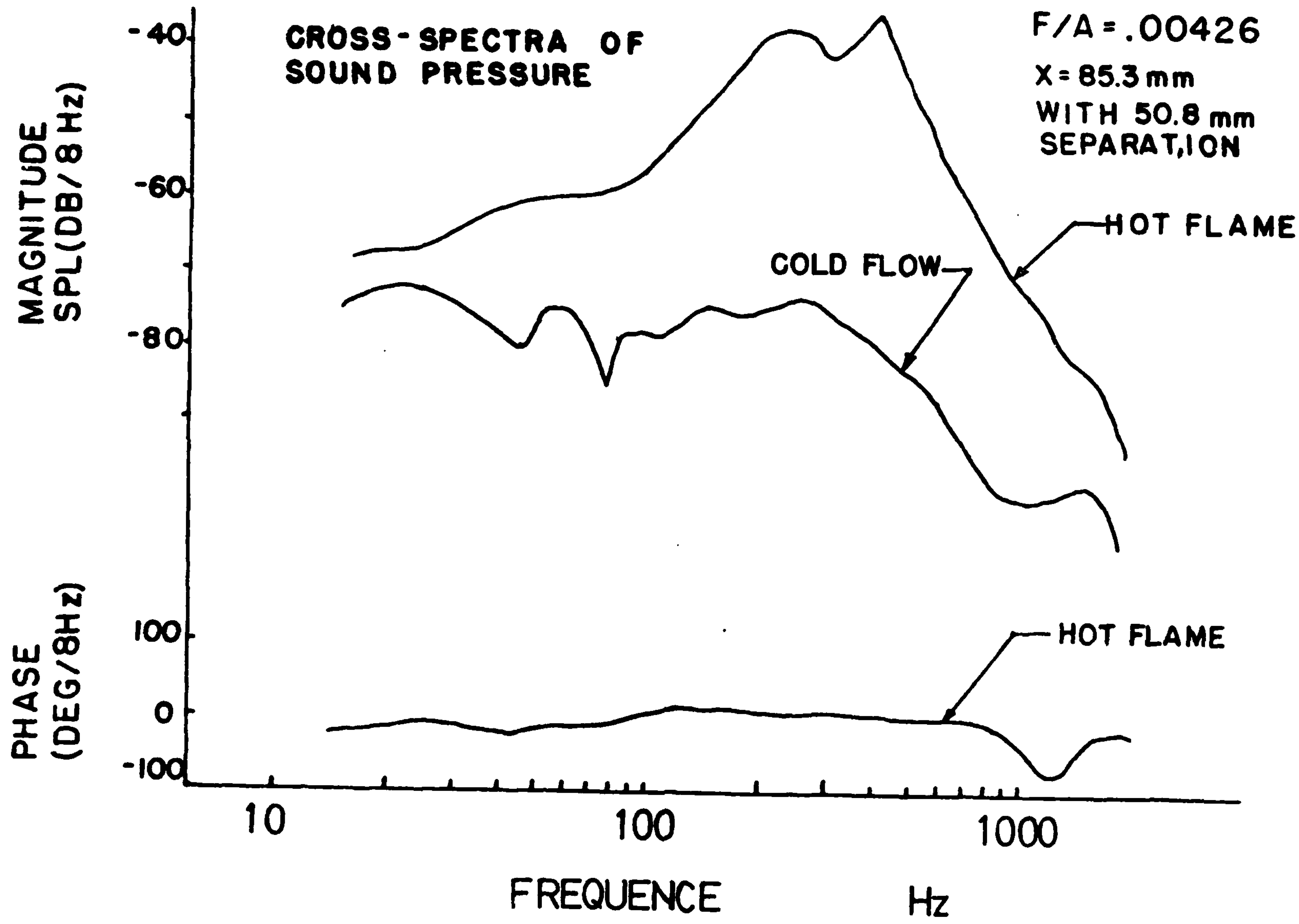
Cutaway view of combustor and schematic of ionization probe.


1.2
x 10^5
1.0
0.8
Sxx
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
X/L
Xp = 0.1 L
0.2 L
0.3 L
FREQ=400 HZ
F(X)=δ(Xp-X)
5.0
x 10^3
4.0
3.0
Sxx
2.0
1.0
0.0
0.0
0.2
0.4
0.6
0.8
1.0
X/L
FREQ=1200 HZ
F(X)=δ(Xp-X)
Xp = 0.1 L
0.2 L
0.3 L



ION
X = 35 mm
F/A = .00426
TOTAL AIR FLOW
= 17.15 KG/MIN
100Hz
400Hz
10
30
50
SEPARATION DISTANCE (mm)
1
0.8
0.6
0.4
0.2
SQUARE ROOT OF COHERENCE


SOUND PRESSURE AUTOSPECTRA
TOTAL AIR FLOW = 17.15 KG/MIN
F/A = .00426
HOT FLAME
COLD FLOW
ELECTRONIC NOISE
X = 32 mm WITH 50.8 mm SEPARATION
-20
-30
-40
-50
-60
1.0
0.5
0.0
S P L (DB/8Hz)
COHERENCE
10
100
1000
FREQUENCY Hz


CROSS-SPECTRA OF
SOUND PRESSURE
F/A = .00426
X = 85.3 mm
WITH 50.8 mm
SEPARAT,ION
HOT FLAME
COLD FLOW
HOT FLAME
MAGNITUDE
SPL(DB/8 Hz)
-40
-60
-80
PHASE
(DEG/8Hz)
100
0
-100
10
100
1000
FREQUENCE
Hz

COMBUSTION AND MICRO-EXPLOSION OF WATER/OIL EMULSIONS IN HIGH-PRESSURE ENVIRONMENTS

C. K. Law

Northwestern University

Water/Oil (W/O) emulsions hold potential for soot reduction, multi-fuel capability, and self-extinguishment upon spillage and incendiary ignition. The present program aims to study the combustion characteristics of W/O emulsion droplets in general, and their behavior in high-pressure environments in particular. Of special interest is the exploration of an explosive droplet combustion phenomenon termed micro-explosion, which may be responsible for much of the potential benefits of emulsion utilization.

The experiment involves injecting a stream of equally-spaced and monodisperse droplets into a co-flowing hot oxidizing gaseous stream. The droplets subsequently ignite and burn. Their combustion behavior are studied via direct photography and sampling. W/O emulsions, alcohol/oil solutions, and miscible fuel blends have been studied.

For the reference case of pure component droplets, we have observed significant temporal variations of the flame-front standoff ratio in accordance with our previously postulated concept of fuel vapor accumulation in the inner region to the flame. Flame extinction also spans a substantial period contrary to the assumption of gas-phase quasi-steadiness.

For two-component fuels with sufficiently different volatilities, a flame shrinkage phenomenon was observed indicating the occurrence of significant droplet heating as the droplet composition becomes more concentrated with the less volatile, higher-boiling-point, components. Severe situations of shrinkage can even lead to droplet extinction.

For three-component fuels consisting of a surfactant, two flame shrinkages occur. Micro-explosion usually take places at the end of the second shrinkage when the droplet becomes highly concentrated with the surfactant.

Preliminary results for pressures up to 5 atmospheres seem to indicate that the occurrence of micro-explosion is enhanced with increasing pressure, although more detailed studies are needed.

Increasing water content up to 30% by volume intensifies micro-explosion. By changing from our macro-emulsions to the Army's micro-emulsion, the explosion intensity is somewhat weakened and the explosion frequently occurs in two stages.

COMBUSTION AND UTILIZATION OF W/O EMULSIONS

- ARMY'S INTERESTS:
  1. FIRE-RESISTANT FUEL
  2. COMBUSTION CHARACTERISTICS IN ENGINES

- ENGINE TESTING RESULTS:
  1. REDUCTION IN SOOT AND NO_x
  2. INCREASED CO AND HC EMISSIONS
  3. EFFECTS ON FUEL ECONOMY INCONCLUSIVE

OBJECTIVES OF PRESENT PROGRAM

- TO UNDERSTAND THE COMBUSTION MECHANISMS OF SINGLE DROPLETS OF W/O EMULSIONS AND MULTICOMPONENT FUEL BLENDS.
- TO FURNISH INFORMATION ON OPTIMIZATION OF FUEL FORMULATION FOR FIRE RESISTENCY AND ENGINE COMBUSTION.
- EMPHASES:
  1. BASIC GASIFICATION MECHANISMS
  2. MICRO-EXPLOSION
  3. HIGH PRESSURE EFFECTS
  4. ALCOHOL BLENDING
  5. SOOT FORMATION.

EXPERIMENTAL METHODOLOGY

- SPECIFICATIONS OF COMBUSTION CHAMBER:

  CONTINUOUS LOW-SPEED FLOW

  MAXIMUM PRESSURE : 20 ATM

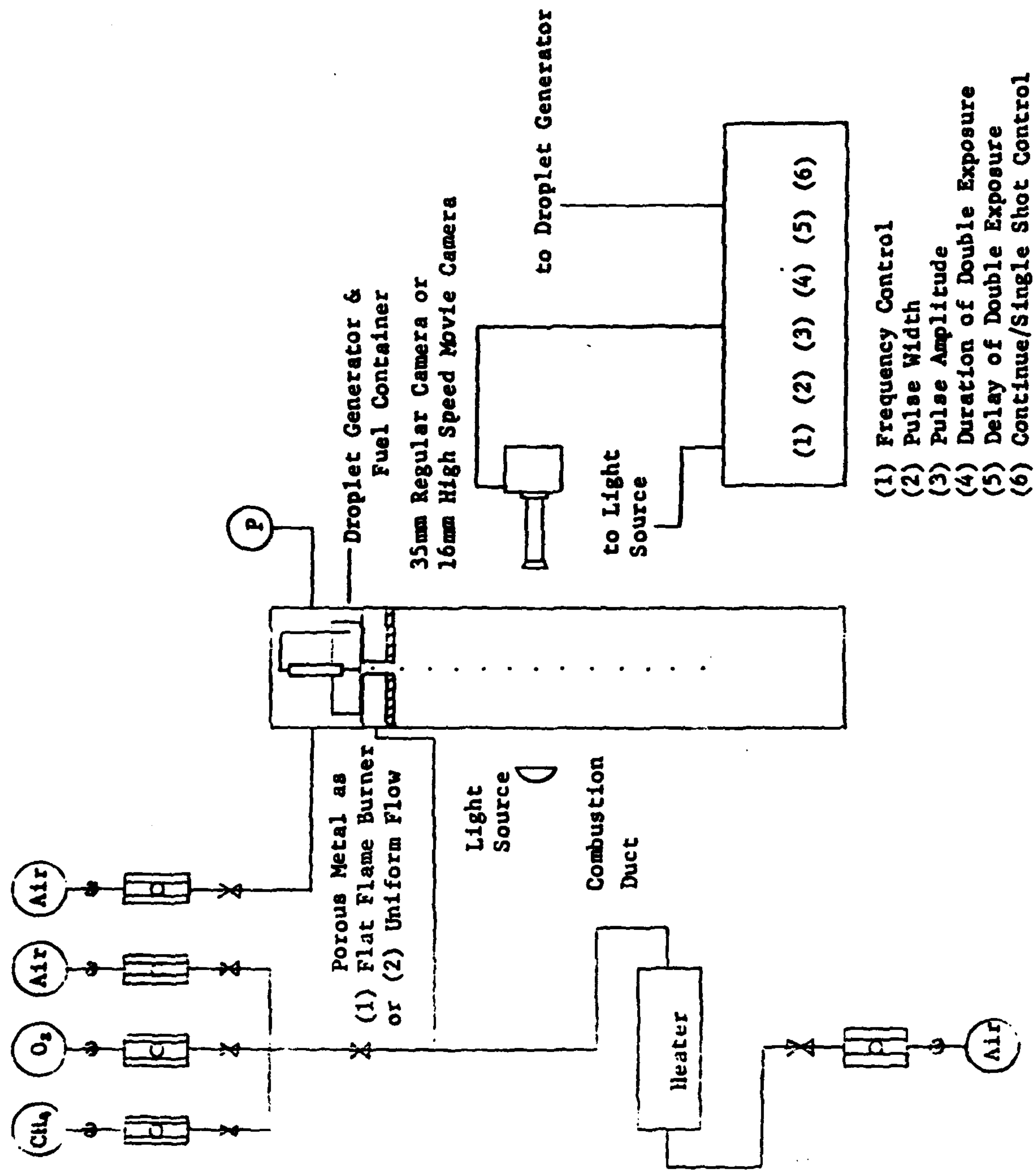
  MAXIMUM TEMP. : 1000 °K

  VARIABLE OXYGEN CONCENTRATION

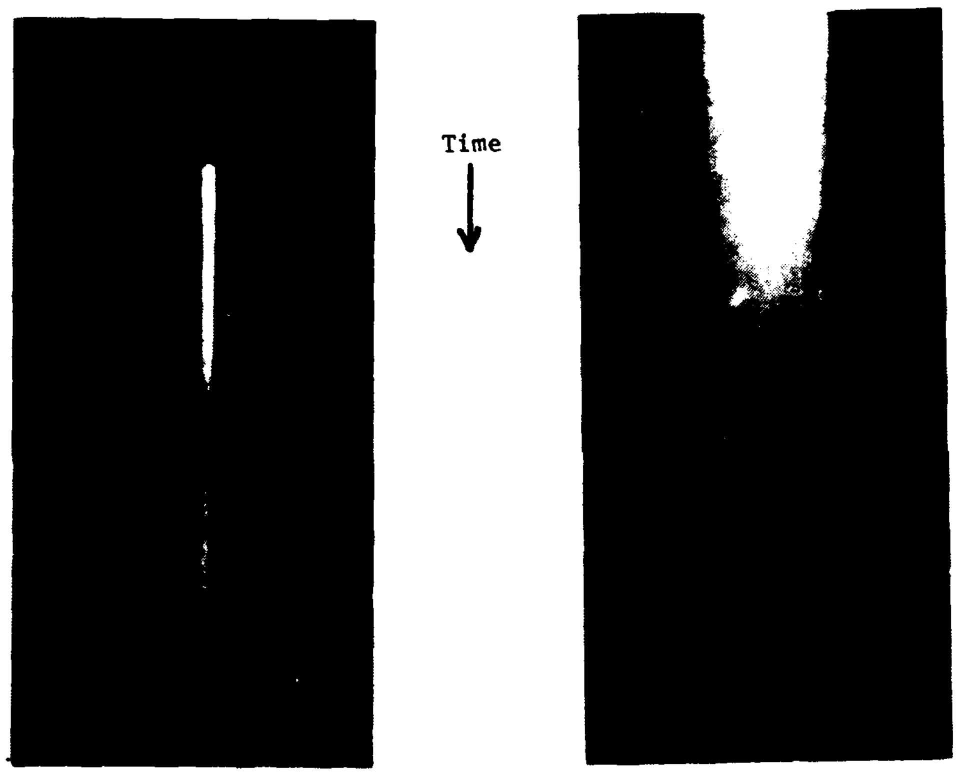
  HOT COMBUSTION ENVIRONMENT PRODUCED THROUGH EITHER RESISTIVE HEATING OR AS COMBUSTION PRODUCT FROM FLAT FLAME BURNER.

- DROPLET PRODUCED BY INK JET PRINTING TECHNIQUE : $100\,\mu m < d_0 < 300\,\mu m$, VARIABLE SPACING , $Re < 1$.

- QUANTITATIVE DATA ACQUIRED THROUGH DIRECT PHOTOGRAPHY & SAMPLING.



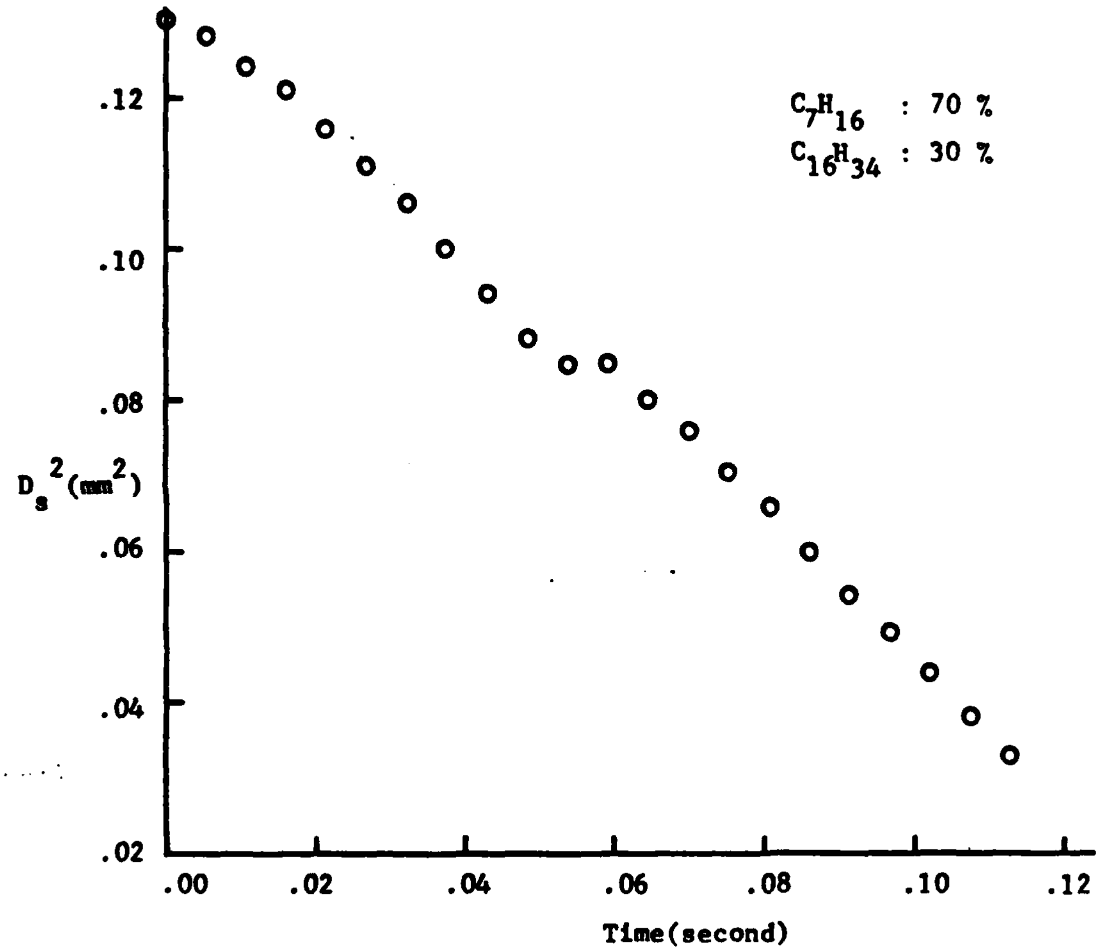
Schematic of the Experimental Apparatus



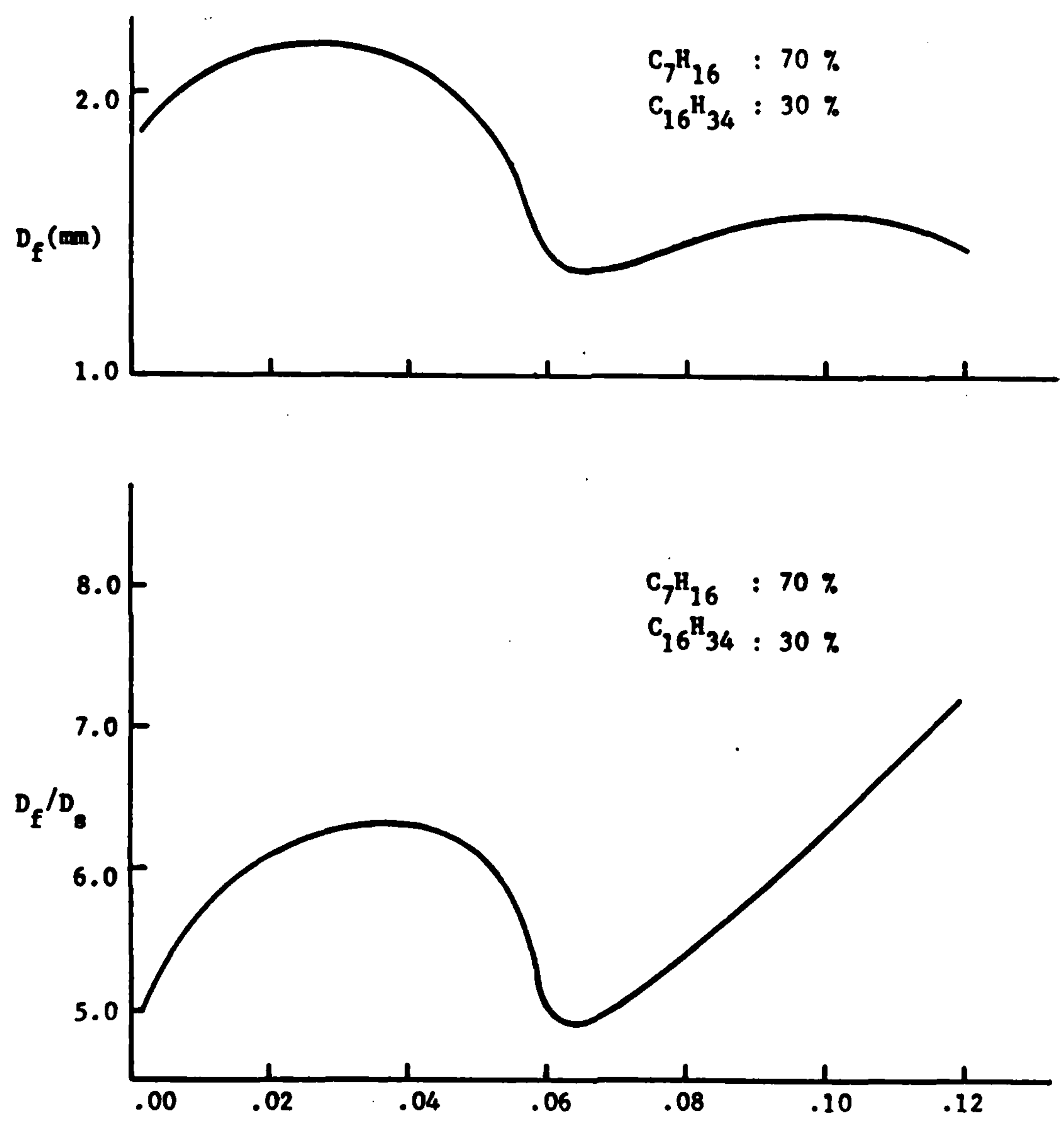
(a)

(b) Enlarged

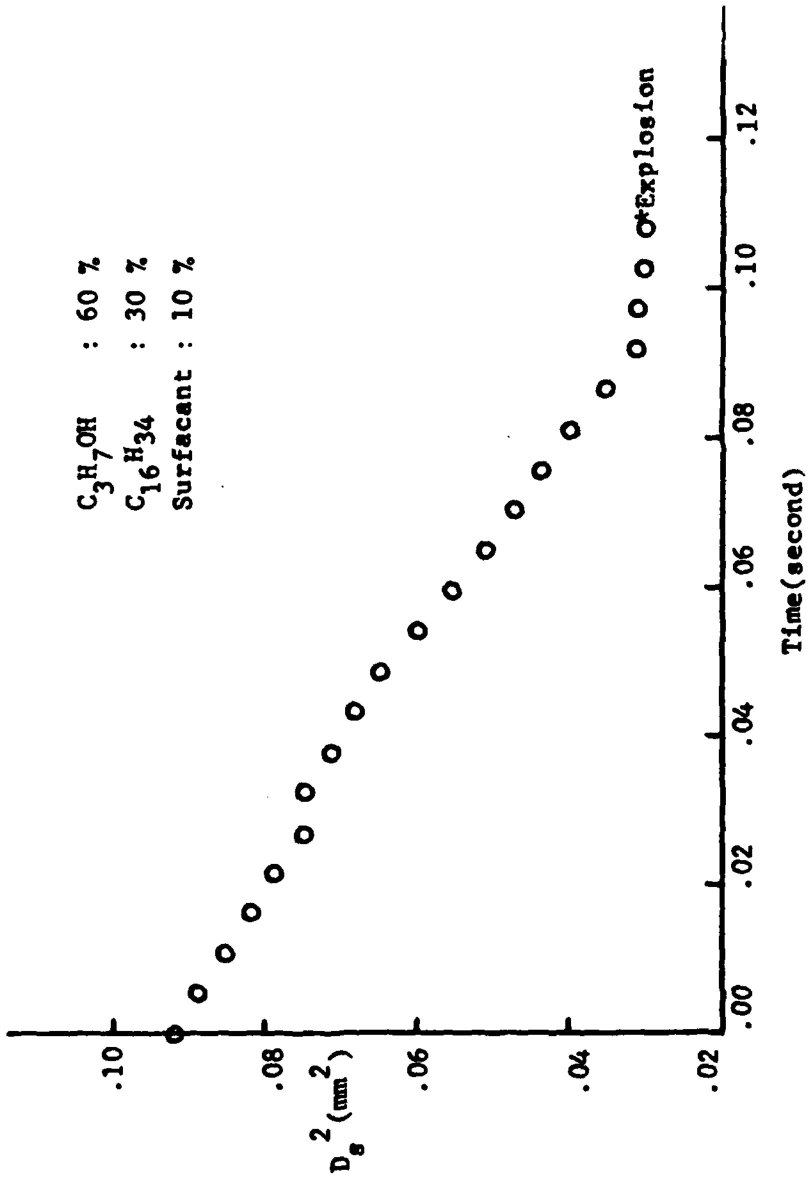
Phenomenon of Flame Shrinkage due to Transitional Droplet Heating



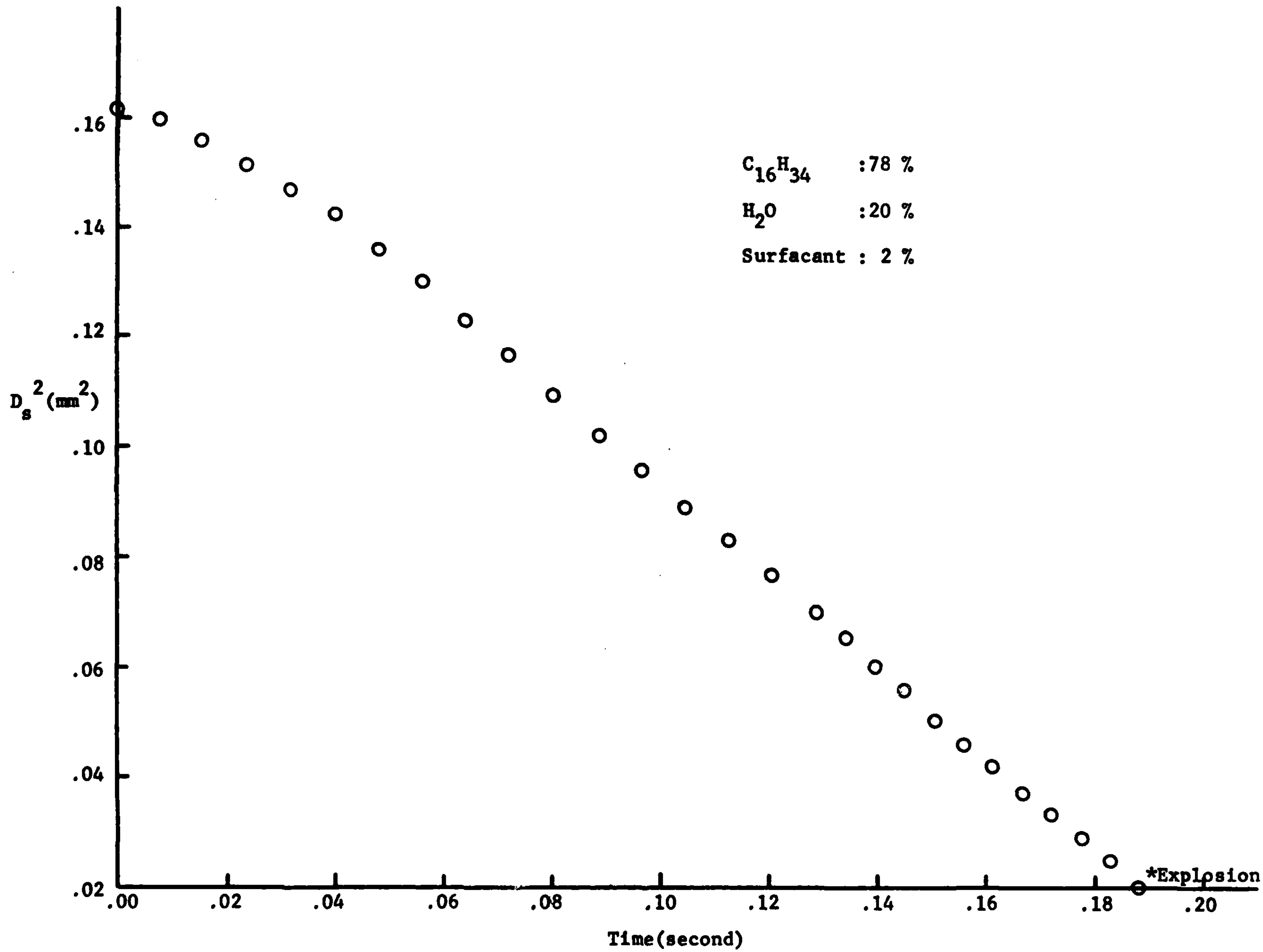
Size History of a Droplet Consisting of 70% Heptane and 30% Hexadecane by Volume



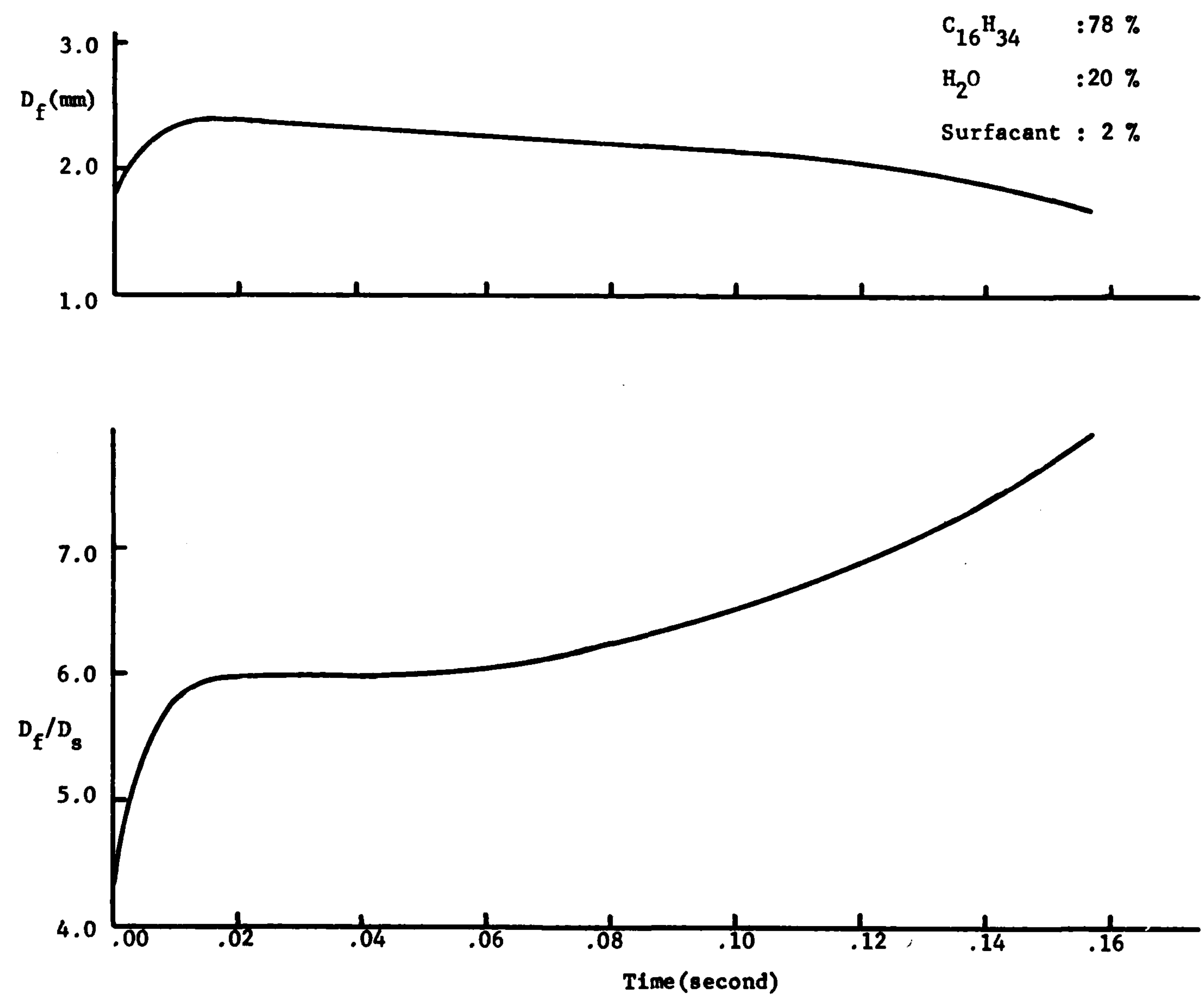
History of Flame Size and Flame-Front Standoff Ratio for a Droplet Consisting of 70% Heptane and 30% Hexadecane by Volume



Size History of a Droplet Consisting of 60% Propanol, 30% Hexadecane, and 10% Surfactant



Size History of a Water/Oil Emulsion Droplet



History of Flame Size and Flame-Front Standoff Ratio of a Water/Oil Emulsion Droplet

Session 5
FUELS/ENGINES TECHNOLOGY

Chairman: F. W. Schaekel
U. S. Army Mobility Equipment Research and Development Command
Fort Belvoir, VA

HOW GUM AND DEPOSITS FORM IN HYDROCARBON FUELS

by

Frank R. Mayo and Bosco Y. Lan
SRI INTERNATIONAL

The object of this research is to determine how and why soluble gum and deposits appear in jet turbine and diesel fuels and thus how to predict and prevent their formation. Oxidations were carried out in air at 130°C. To focus attention on inherent stabilities of fuels and to avoid effects of previous storage, all fuels were distilled in vacuum before use and stored under nitrogen at -12°C. Oxidation is required for gum or deposit formation. The hydroperoxides formed cause step-wise coupling of fuel molecules to heavier products. Whether these remain in solution depends on the solvent properties of the fuels. Since our work was reported to the Division of Fuel Chemistry at the March 1982 ACS Meeting, experiments with dodecane and a jet turbine fuel have shown how small proportions of indene or N-methylpyrrole greatly increase rates of gum formation (and are thereby soon exhausted), with either an increase or a decrease in the rate of oxygen absorption.

The major remaining problems are the effect of oxygen concentration on gum formation, determination of which fuel components lead to stability and instability, and the relative importance of gum formed on storage and by very rapid oxidation and condensation in hot engine zones.

HOW GUM AND DEPOSITS FORM IN HYDROCARBON FUELS

Frank R. Mayo and Bosco Y. Lan, SRI International

Object: To determine how and why soluble gum and deposits appear in jet turbine and diesel fuels, and thus how to predict and prevent their formation.

1

SUMMARY OF PREVIOUS WORK AT SRI INTERNATIONAL

Rates of oxidation and gum formation (new method) were measured in air at 130°C.

Gum is formed by stepwise condensation of oxidation products of fuel by hydroperoxides.

Whether gum formation leads to deposit formation depends on the solvent properties of the fuel.

Among different fuels, there is no correlation between deposit formation and rate of oxidation.

In different oxidations of the same fuel, gum formation is proportional to rate of oxidation.

2

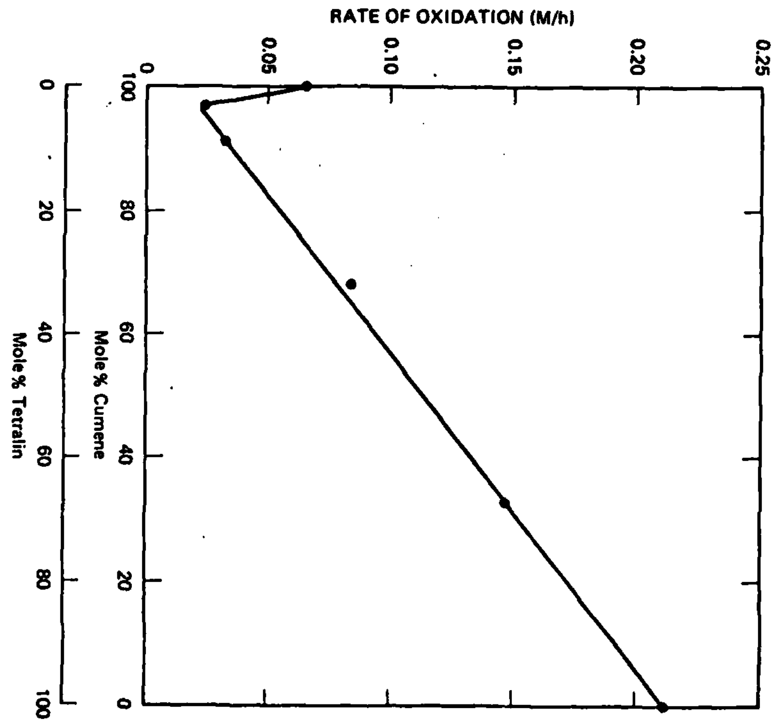


FIGURE 3 COOXIDATION OF CUMENE AND TETRALIN WITH 0.02 M t-BuO_2Bz AT 90°C
Data of G. A. Russell.[8]

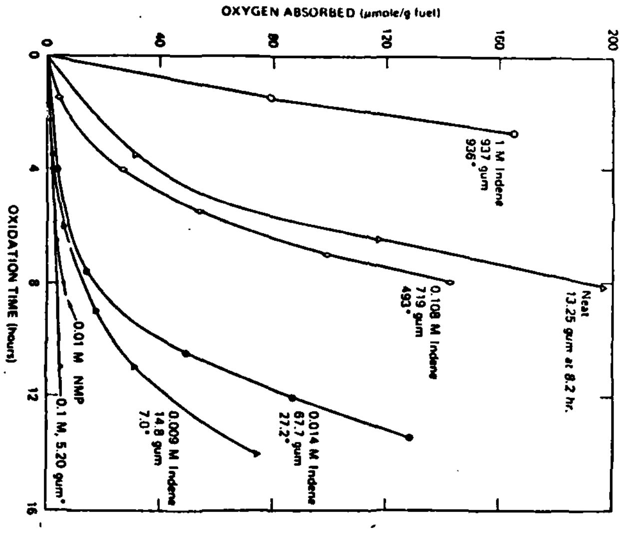


FIGURE 4 OXIDATIONS OF n-DODECANE WITH INDENE AND NMP AT 130°C
Gum is in mg/100 g fuel, determined at 100°C except when marked * for 200°C.

JA-2115-16A

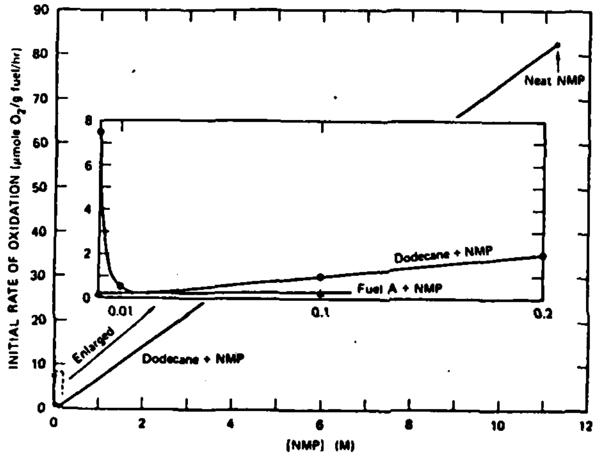


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FIGURE 5 INITIAL RATES OF OXIDATION OF FUEL A AND n-DODECANE WITH NMP AT 130°C

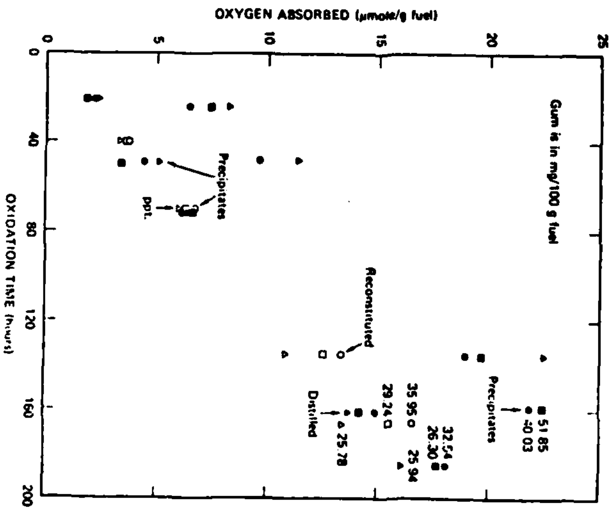


FIGURE 6 OXIDATION OF FUEL 10 IN AIR AT 130 C

JA-1974-11

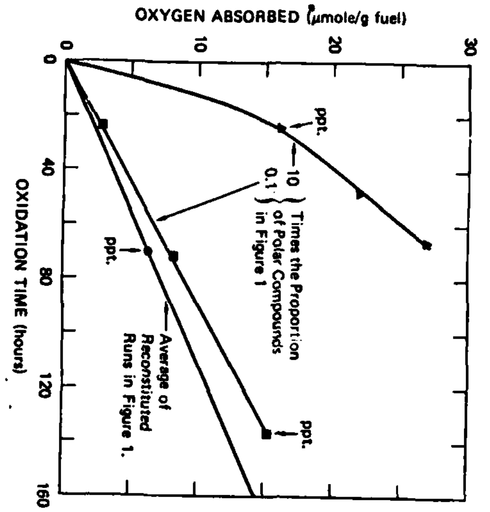


FIGURE 7 OXIDATION OF RECONSTITUTED FUEL 10 AT 130°C IN AIR WITH 0.1, 1, AND 10 TIMES ORIGINAL PROPORTION OF POLAR COMPOUNDS

CONCLUSIONS

Gum and deposits are closely associated with oxidation of fuel.

Gum and deposits incorporate the fuel components that are most susceptible to oxidation and are consumed rapidly.

The reactive components usually increase gum formation, but they may increase or decrease the rate of oxygen absorption, depending on their proportions in the fuel.

8

SOME REMAINING PROBLEMS

What components most affect fuel stability?

What is the effect of oxygen pressure on gum and deposit formation?

Do deposits on hot engine parts come mostly from gum formed in storage or from sudden oxidation near the hot metal?

How applicable are our results and conclusions at 130°C to service conditions?

Do soluble metals and metal surfaces play important parts in gum and deposit formation?

9

AFLRL Basic Research on Fuel Storage Stability

G. H. Lee
L. L. Stavinoha
U. S. Army Fuels and Lubricants Research Laboratory
Southwest Research Institute
San Antonio, TX

ABSTRACT

This program was started as a 3-year study under 6.1 funding by USAMERADCOM in October 1981. Its major objective is to determine the primary chemical reaction mechanisms causing "insoluble" particulate matter and adherent gums to form in neat and additive-treated middle distillate fuels. Reaction kinetics and variations in chemical composition of the degradation products are being determined through accelerated aging at 65°, 80°, and 95°C in both large (30-gallon) and small (200 cc) containers. The weight of "insoluble" particulate matter per liter of fuel is determined as a function of time using ASTM D 2276 techniques. The rate of particle growth will be determined using instrumentation capable of measuring in the 0.5- to 90-μm range.

Characterization of the chemical functionalities constituting the particulates and gums is being studied, following chromatographic separation, by infrared spectrophotometry, mass spectrometry, nuclear magnetic resonance, and other techniques as appropriate.

AFLRL DISTILLATE FUEL–RELATED ACTIVITIES

- BASIC RESEARCH →
  - MECHANISM OF DEGRADATION AND ADDITIVE INHIBITION
  - FUEL CONTAINER/FUEL STABILITY INVOLVEMENT
- TEST TECHNIQUE DEVELOPMENT →
  - FIELD TEST TECHNIQUES →
    - QUALITY
    - PREDICT FUTURE QUALITY
  - LABORATORY TEST TECHNIQUES →
    - QUALITY, PREDICTION
    - FUEL SYSTEM DEBRIS IDENTIFICATION
    - INJECTOR FOULING BENCH TEST
- SURVEY FUELS →
  - WORLD WIDE FUEL QUALITY ASSESSMENT
  - REFINERY → LABORATORY METHODS CORRELATION → SPECIFICATIONS, FIELD MANUALS, ETC.
  - REFERENCE/REFEREE FUEL DEFINITION
- BETC TEST TECHNIQUE DEVELOPMENT →
  - SURVEY AND TECHNIQUE OPTIMIZATION (COMPLETED)
  - SYNTHETIC FUEL STABILITY
  - SOURCE OF FUEL STABILITY INFORMATION & TESTING
- DOE, SPRO, CRUDE AND PRODUCT STORAGE →
  - STATE OF THE ART REVIEW (COMPLETED)
  - QUALITY ASSESSMENT (COMPLETED)
- ASTM D–2, E–V STABILITY AND CLEANLINESS →
  - SYMPOSIUM (STP751) (COMPLETED)
  - METHODS DEVELOPMENT
  - APPENDICES TO SPECIFICATIONS
- ADDITIVES FOR DEPOT USE →
  - YUMA PG TEST (LIMITED) AND POMCUS TEST (COMPLETED)
  - MARINE CORP. NTPS TEST
  - LETTERKENNY ARMY DEPOT (PROPOSED)
  - DOD–S STABILIZER ADDITIVE SPEC.
- VOLATILE CORROSION INHIBITORS FOR FUELS/FUEL TANKS IN VEHICLE (PROPOSED)
- FIELD PROBLEM SURVEILLANCE →
  - FORT HOOD
  - FORT RILEY
  - PATRIOT MISSILE (WHITE SANDS)
  - FORT POLK
  - ARMY DEPOTS, ETC.
- VEHICLE FUEL FILTER →
  - SAE J–905 TEST RIG DEFINITION
  - FIELD LIMITING VALUES (PROPOSED)
  - LABORATORY–FIELD CORRELATION (PROPOSED)
- PUBLIC/TECHNICAL RELATIONS →
  - ASTM COMMITTEE D–2
  - MAINTENANCE COUNCIL OF AMERICAN TRUCKING ASSOCIATION
  - DARCOM CORROSION GROUP
  - CONFERENCES
  - DTIC PUBLICATIONS

FUEL DETERIORATION AND ADDITIVE INHIBITION MECHANISMS

6.1/AH51FG (3)

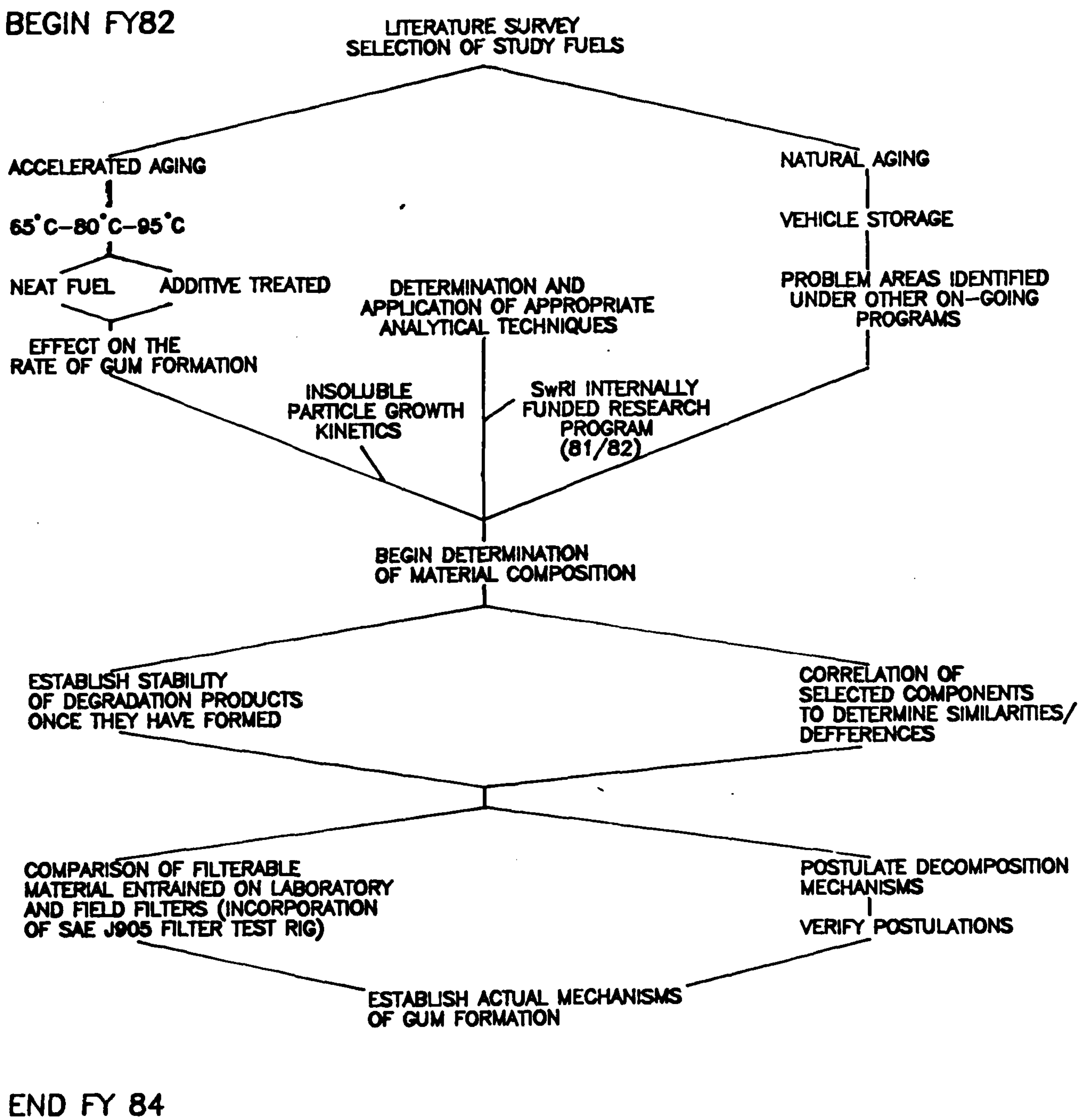
OBJECTIVE:

TO INVESTIGATE THE MECHANISM OF MIDDLE DISTILLATE FUEL DETERIORATION THROUGH CHEMICAL CHARACTERIZATION OF THE MATERIALS INVOLVED AFTER APPLICATION OF VARIOUS ACCELERATED AGING TECHNIQUES

APPROACH:

1. REVIEW AND ASSEMBLE PERTAINENT LITERATURE ARTICLES.
2. SELECT APPROPRIATE TEST FUELS.
3. AGE THE CHOSEN TEST FUELS (WITH AND WITHOUT ADDITIVES) USING PROVEN METHODS.
4. COLLECT AND CHEMICALLY ANALYZE "SOLUBLE" AND "INSOLUBLE" DEGRADATION PRODUCTS.
5. FROM THE CHEMICAL STRUCTURES (CLASSES) DETERMINED, FORMULATE VIABLE DETERIORATION MECHANISMS AND COMPARE TO THOSE SUGGESTED IN LITERATURE.

PLANS FOR DEVELOPMENT OF AH51FG (3)



FINDINGS

1. Solubility of filterable particulates changes with time after filtration.

2. Benzene solubles appear to have ester character.

3. Pyridine solubles are probably nitrogen containing, non–ester compounds.

4. The major products appear to be salts such as sulfates or sulfonates even though GPC appears to indicate MW's of up to approximately 1500.

5. Adherent gum formation does not occur (in "large" scale aging) until after insoluble particulates form. This is not necessarily true in small scale aging.

6. The sum of adherent gum weight and insoluble particulate weight appears to increase at the same rate as the insoluble particulates prior to adherent gum formation (large scale).

7. Degradation products appear to be very similar thus being independent of the source or additive.

BASIC RESEARCH ON FIRE-RESISTANT DIESEL FUEL

W. D. Weatherford, Jr.
D. W. Naegeli
U. S. Army Fuels and Lubricants Research Laboratory
Southwest Research Institute
San Antonio, Texas

ABSTRACT

Measurements of flammability limits of diesel fuel vapors in air diluted with various amounts of water vapor have established that such mixtures containing more than about 24 vol% water vapor cannot burn.

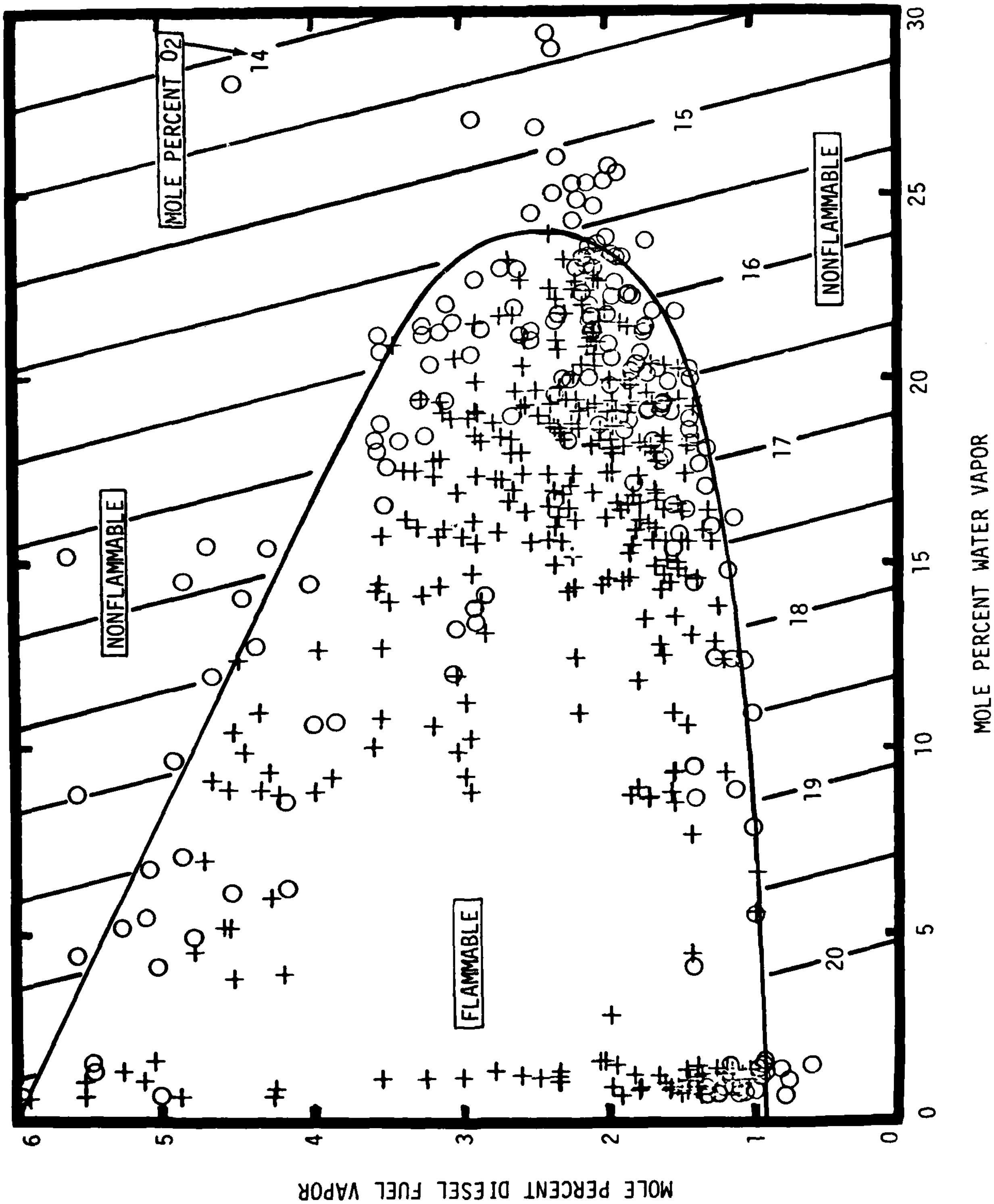
Vapor pressure measurements confirmed that FRF systems containing 10 vol% water are blanketed by equilibrium vapors containing at least 24 vol% water for liquid temperatures greater than about 70°C. Moreover, the same ratio of surfactant to water yields the same equilibrium vapor water content with FRF containing either more or less than 10 percent water.

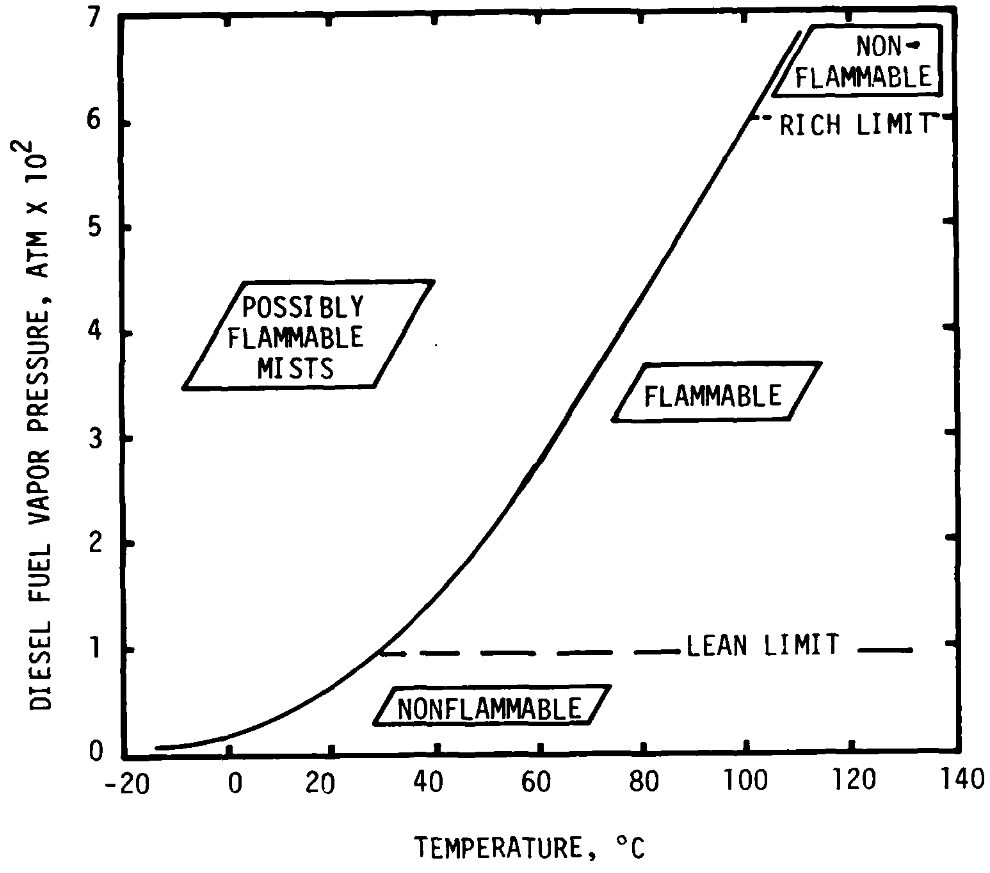
Vapor pressure measurements indicate that FRF blends containing 6 vol% surfactant and between about 2 and 10 vol% water are true microemulsions which exert equilibrium water partial pressures significantly less than that of pure water. When the water content is less than about 1 vol%, these systems appear to be micellar solutions with even lower equilibrium water partial pressures.

The flash points of DF-2-type FRF blends containing 10 vol% water were about the same as those of the neat fuel when the flash point was less than about 70°C. When the flash point of the base fuel exceeded 70°C, a flash point for the FRF was not detectable. For these FRF blends at temperatures above 70°C, the partial vapor pressure of water is higher than the 24-percent vapor phase composition limit for flammability.

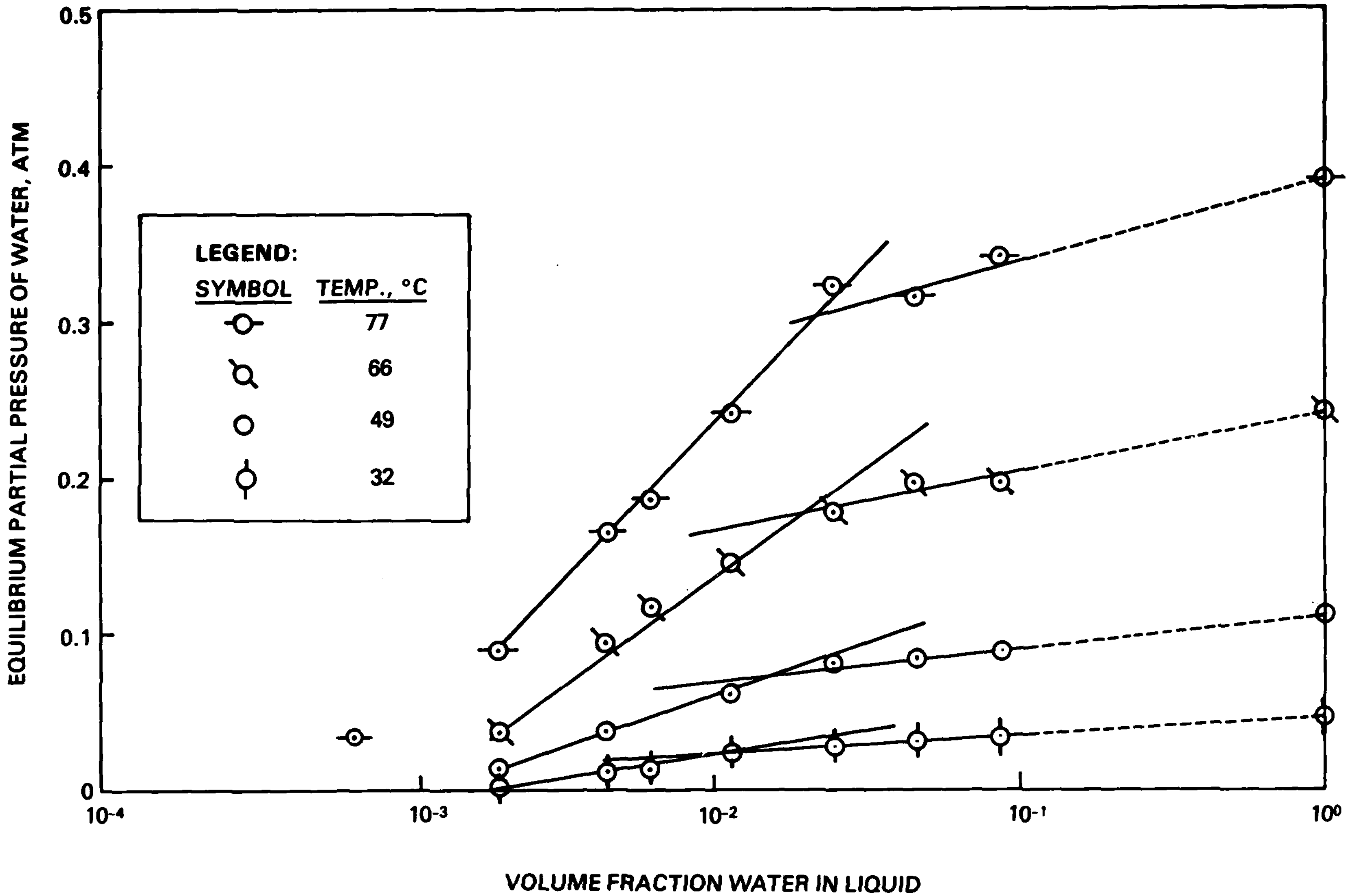
Horizontal flame channel experiments indicate that the lowest water content which prevents vapor burning in dynamic (i.e., nonequilibrium) situations is between 0.5 and 5 vol% in the liquid.

A special apparatus was developed to measure liquid-surface evaporative cooling and liquid-surface-flow heating effects in the vicinity of a simulated flame on the FRF surface. The results confirmed that evaporative cooling effects are significant, but that they are not responsible for the self-extinquishing properties of FRF. In fact, the data indicate that the surface-flow effects in front of the simulated flame (Marangoni effect) provide sufficient surface heating to generate the greater than 24 vol% water vapor composition needed for self-extinguishment even when the bulk liquid FRF is much cooler than 70°C.

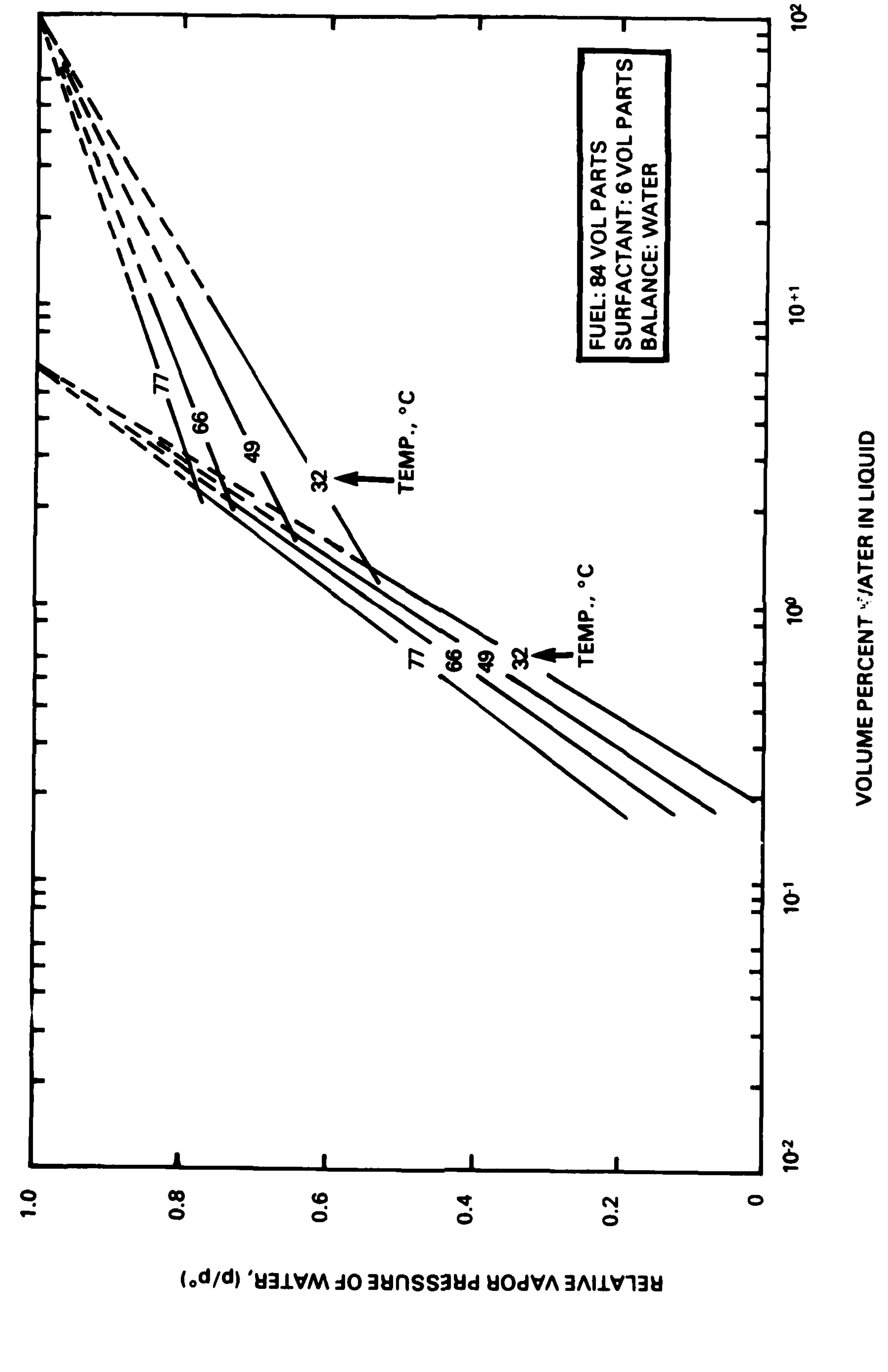

MOLE PERCENT O_2
14
15
16
17
18
19
20
NONFLAMMABLE
NONFLAMMABLE
FLAMMABLE
MOLE PERCENT WATER VAPOR
0
5
10
15
20
25
30
MOLE PERCENT DIESEL FUEL VAPOR
0
1
2
3
4
5
6



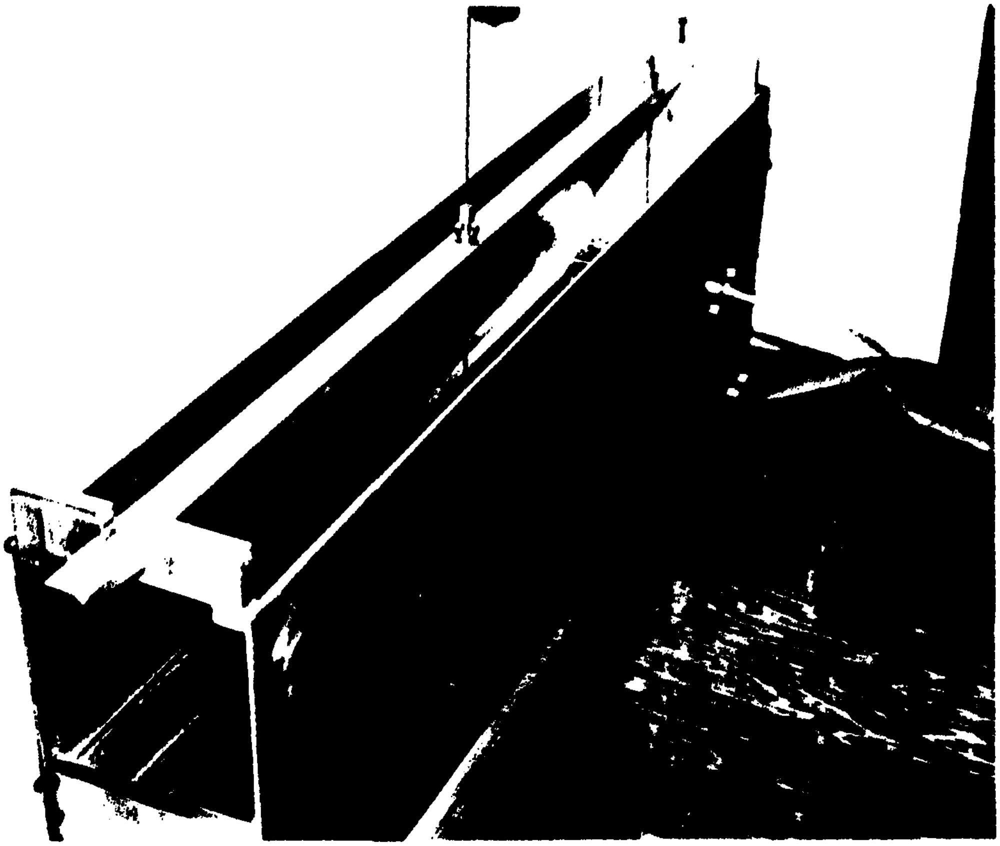
VAPOR PRESSURE-FLAMMABILITY DIAGRAM
FOR A TYPICAL DIESEL FUEL

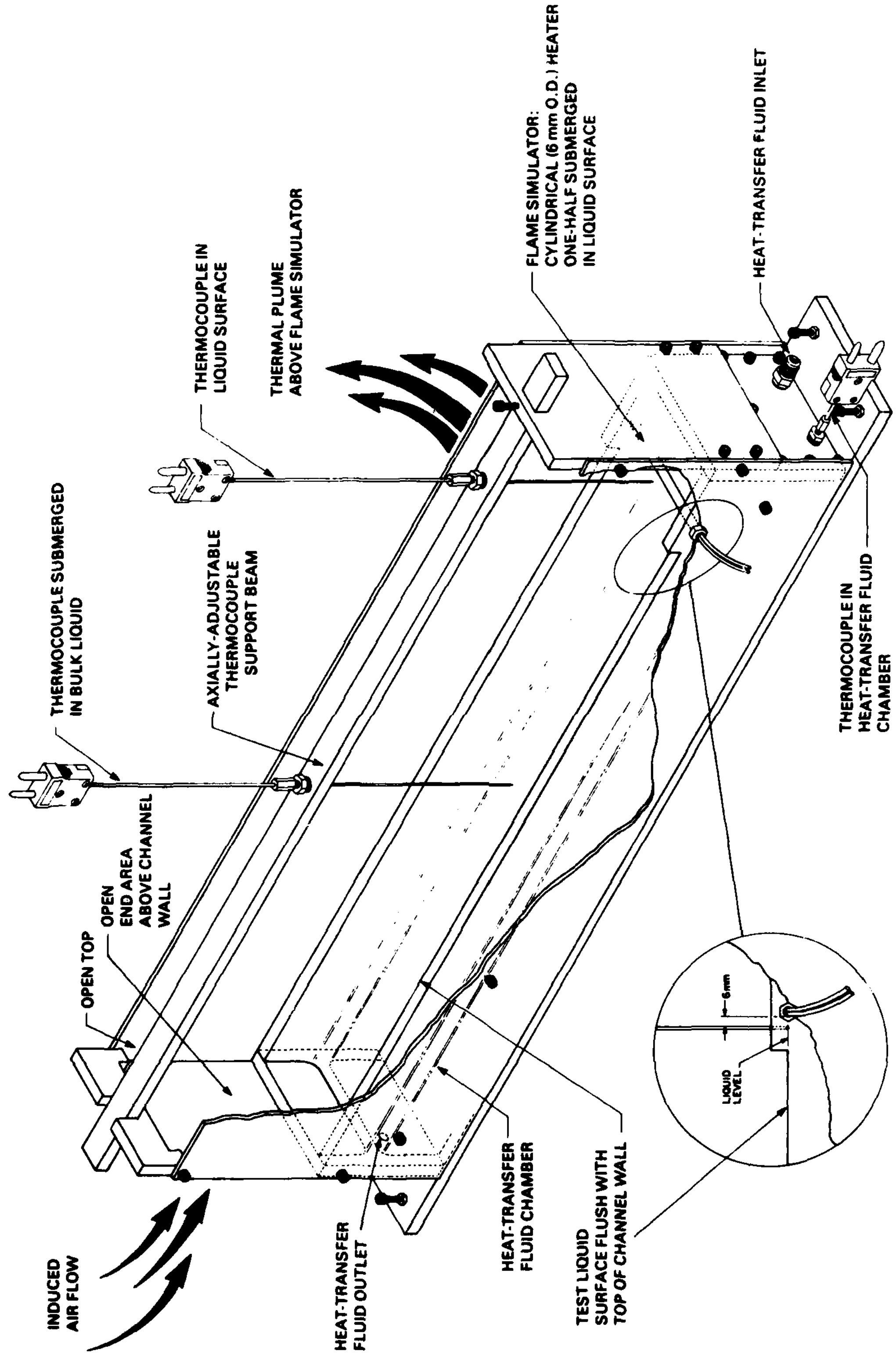


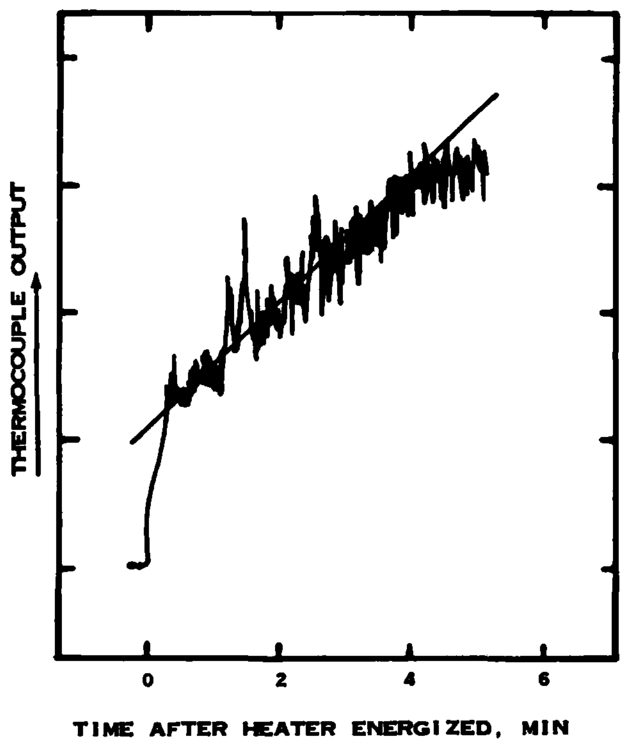
VAPOR-LIQUID EQUILIBRIA OF WATER/SURFACTANT/DIESEL FUEL BLENDS
(84 vol parts DF-2 Fuel/6 vol parts Amine/Amide ^ rfactant)



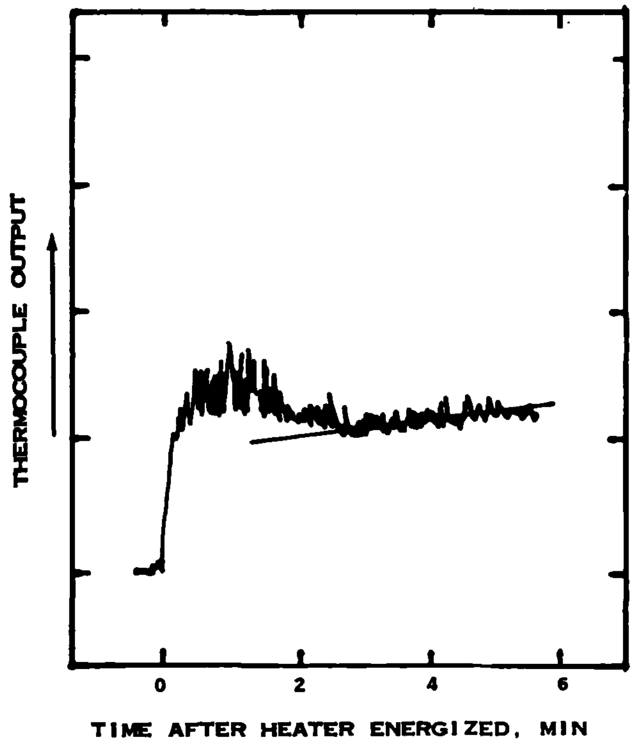
FUEL: 84 VOL PARTS
SURFACTANT: 6 VOL PARTS
BALANCE: WATER
77
66
49
32
TEMP., °C
77
66
49
32
TEMP., °C
10^-2
10^-1
10^0
10^+1
10^2
VOLUME PERCENT WATER IN LIQUID
0
0.2
0.4
0.6
0.8
1.0
RELATIVE VAPOR PRESSURE OF WATER, (p/p°)



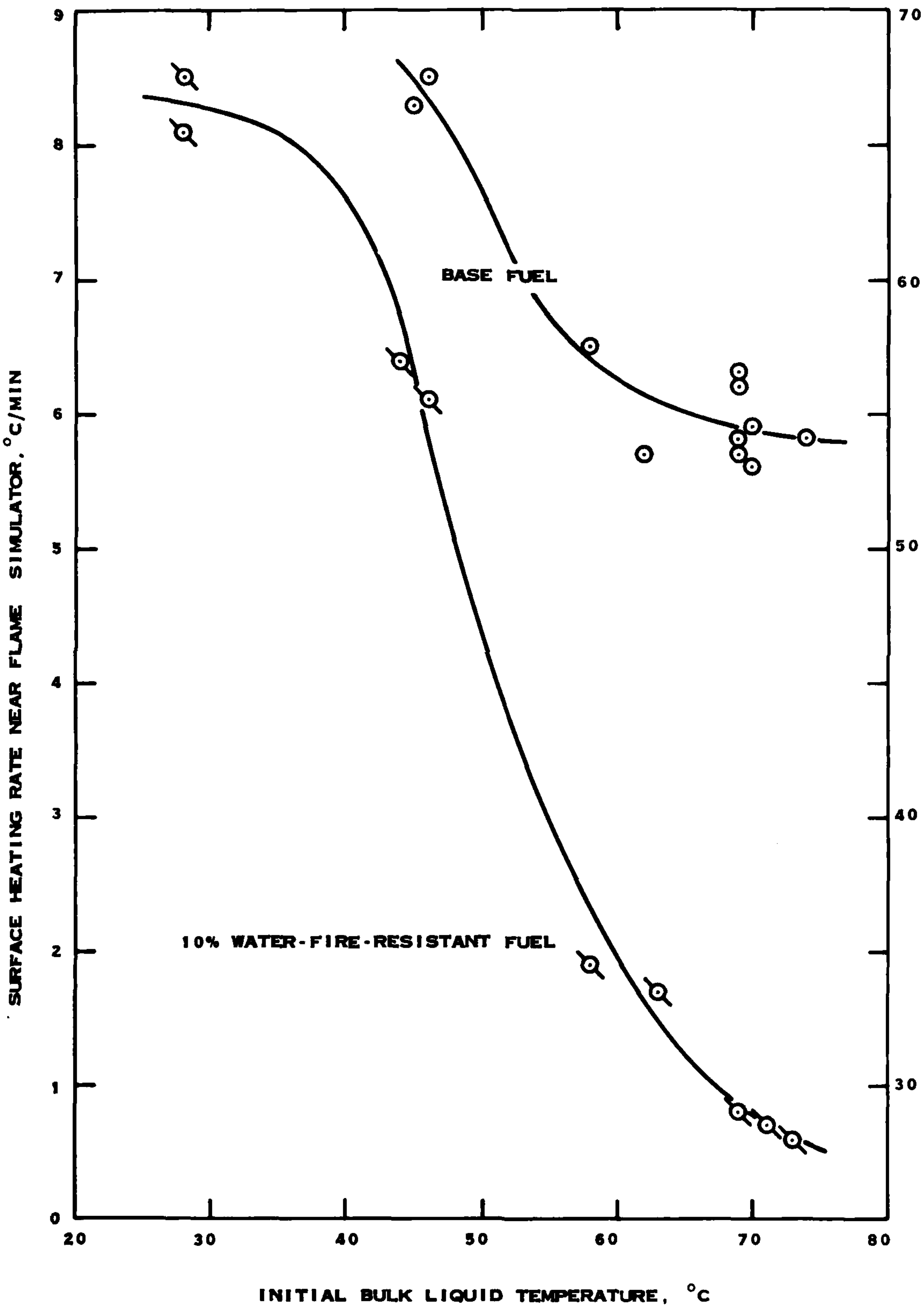

INDUCED AIR FLOW
HEAT-TRANSFER FLUID OUTLET
HEAT-TRANSFER FLUID CHAMBER
TEST LIQUID SURFACE FLUSH WITH TOP OF CHANNEL WALL
OPEN TOP
OPEN END AREA ABOVE CHANNEL WALL
THERMOCOUPLE SUBMERGED IN BULK LIQUID
AXIALLY-ADJUSTABLE THERMOCOUPLE SUPPORT BEAM
THERMOCOUPLE IN LIQUID SURFACE
THERMAL PLUME ABOVE FLAME SIMULATOR
FLAME SIMULATOR: CYLINDRICAL (6 mm O.D.) HEATER ONE-HALF SUBMERGED IN LIQUID SURFACE
HEAT-TRANSFER FLUID INLET
THERMOCOUPLE IN HEAT-TRANSFER FLUID CHAMBER
LIQUID LEVEL
6mm

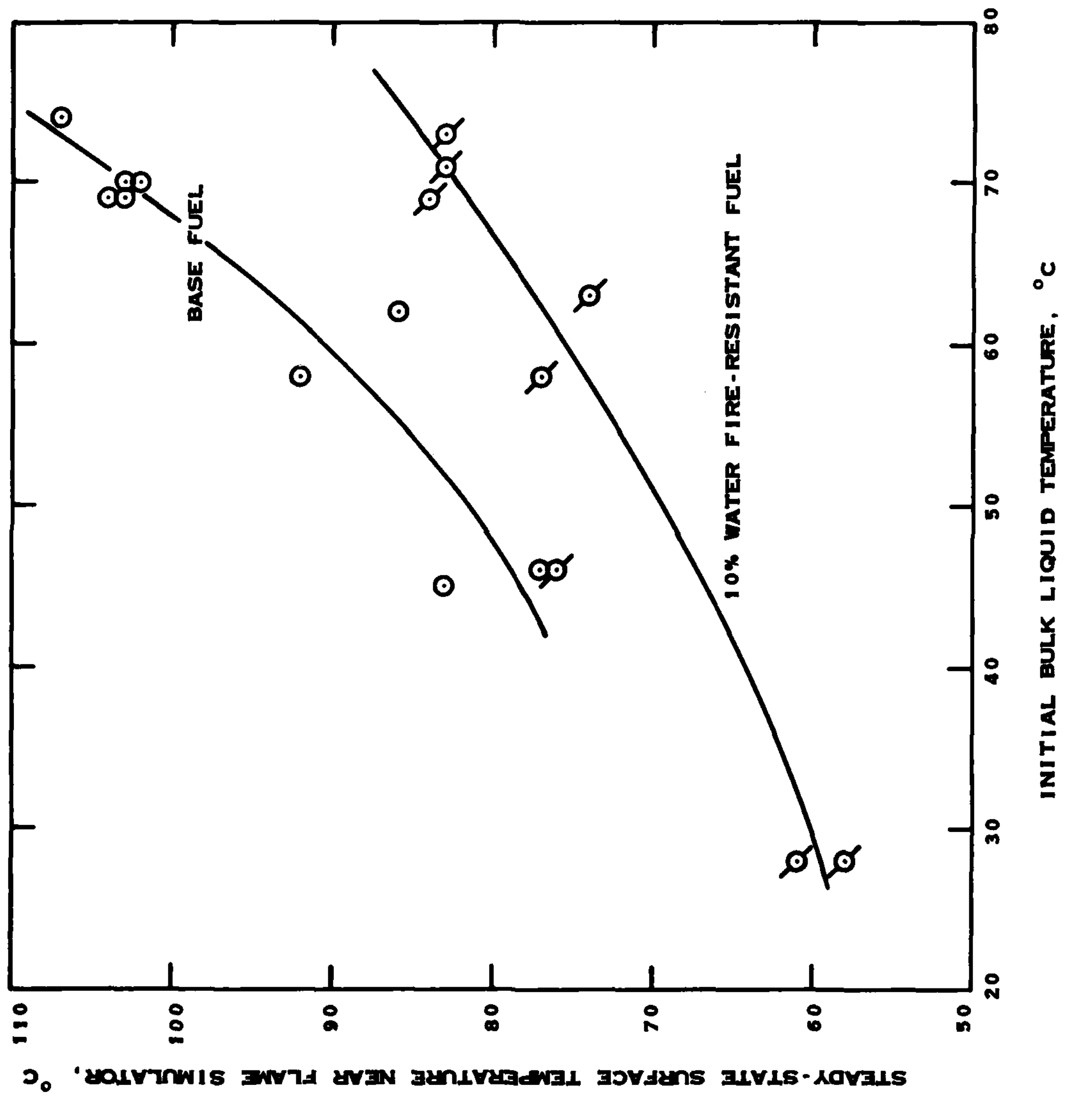


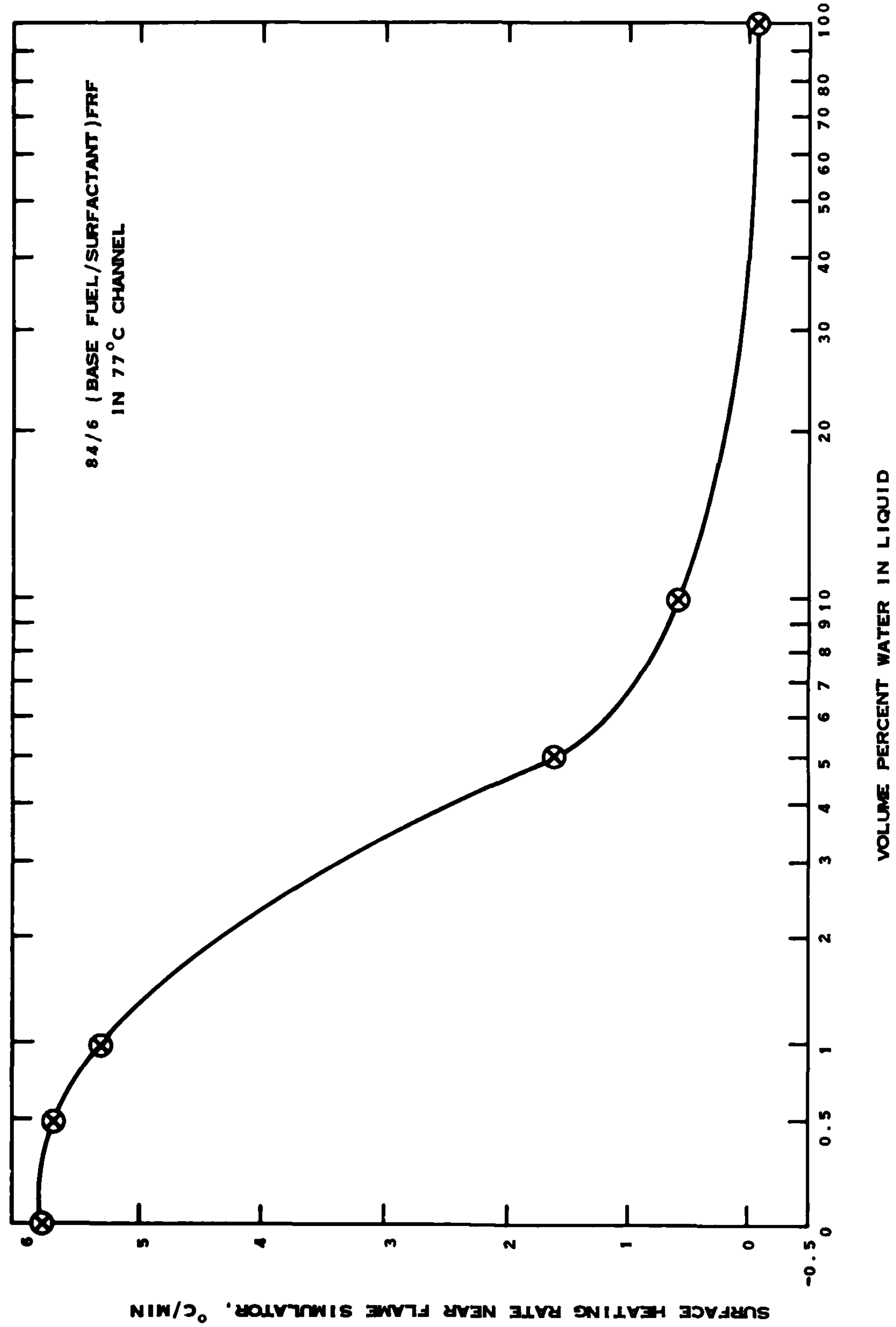
A. NEAT FUEL AT 74°C INITIALLY



B. FRF AT 74°C INITIALLY


BASE FUEL
10% WATER-FIRE-RESISTANT FUEL
SURFACE HEATING RATE NEAR FLAME SIMULATOR, °C/MIN
INITIAL BULK LIQUID TEMPERATURE, °C
0
1
2
3
4
5
6
7
8
9
20
30
40
50
60
70
80
30
40
50
60
70


BASE FUEL
10% WATER FIRE-RESISTANT FUEL
INITIAL BULK LIQUID TEMPERATURE, °C
20 30 40 50 60 70 80
STEADY-STATE SURFACE TEMPERATURE NEAR FLAME SIMULATOR, °C
50 60 70 80 90 100 110


84/6 (BASE FUEL/SURFACTANT)FRF
IN 77°C CHANNEL
SURFACE HEATING RATE NEAR FLAME SIMULATOR, °C/MIN
VOLUME PERCENT WATER IN LIQUID
6
5
4
3
2
1
0
-0.5
0
0.5
1
2
3
4
5
6
7
8
9 10
20
30
40
50
60
70
80
100

SYNOPSES OF RELATED BASIC RESEARCH AT SwRI

T.W. Ryan, III
Department of Fuels and Lubrication Technology
Southwest Research Institute
San Antonio, Texas

ABSTRACT

Four areas of basic research which are currently being addressed within the Energy Systems Research Division of SwRI are:

- injection and atomization in diesel engines;
- combustion of fuels in diesel engines;
- spray and evaporation of fuels in turbine engines;
- injection and atomization of two-phase fuels.

Work in these areas require extensive facilities, including various specialized engines, bombs and flow devices, as well as state-of-the-art diagnostic systems including the latest in laser and real-time computer technology.

Four different SwRI projects, one in each of the areas listed above, are described briefly. The emphasis in most cases is placed on a description of the facilities being used in the particular project. Examples of the experimental results from each project are presented.

TOPICS OF DISCUSSION

- PICTURE WINDOW ENGINE
- ENGINE COMBUSTION/IGNITION FACILITY
- ATOMIZATION OF EMULSIFIED FUELS IN CONTINUOUS COMBUSTION SYSTEMS
- CARBON SLURRY FUEL DEVELOPMENT

PICTURE WINDOW ENGINE FACILITY

FACILITY DEVELOPED BY

C. D. WOOD

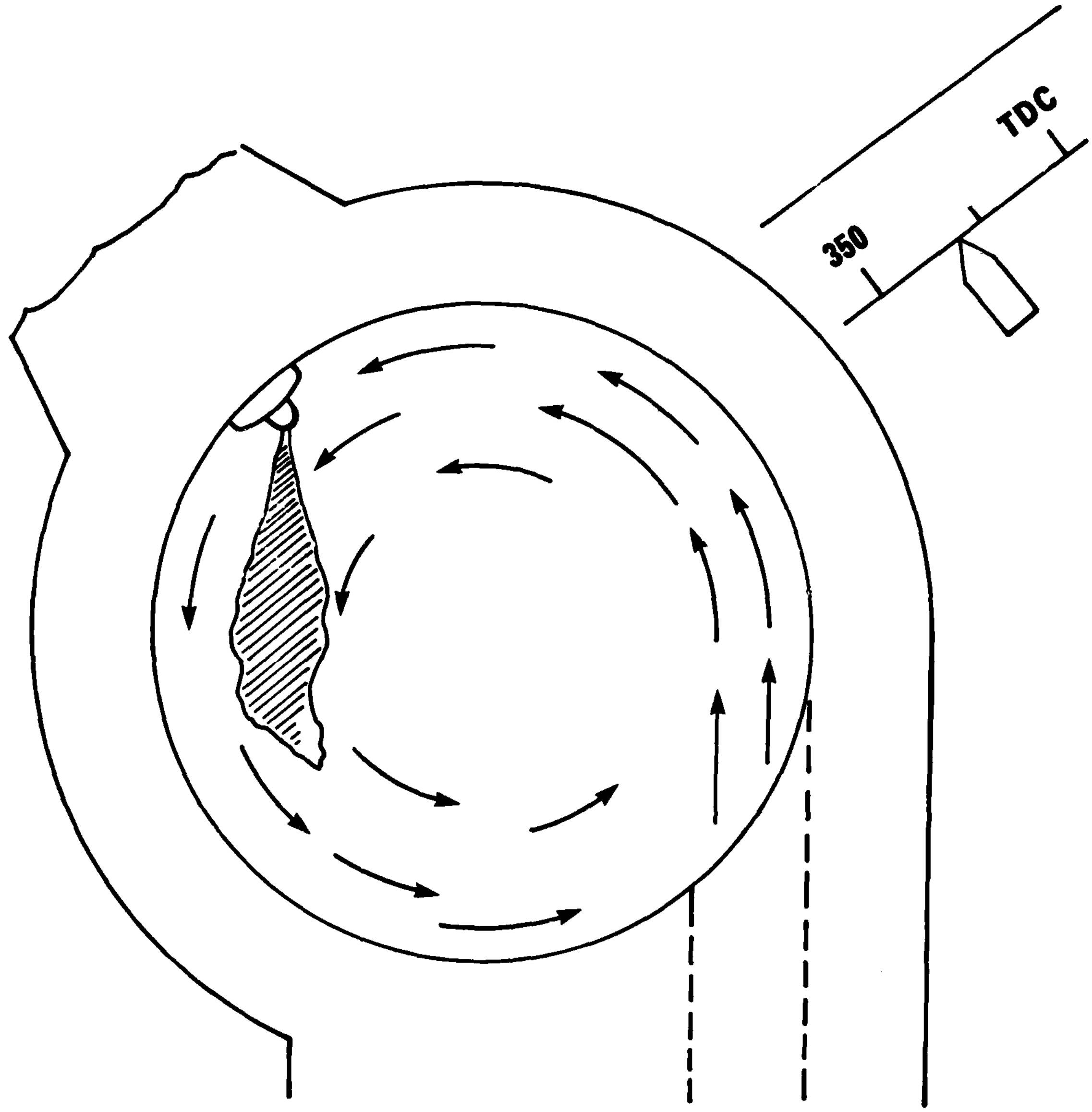
J. O. STORMENT

DEPARTMENT OF ENGINE AND VEHICLE RESEARCH

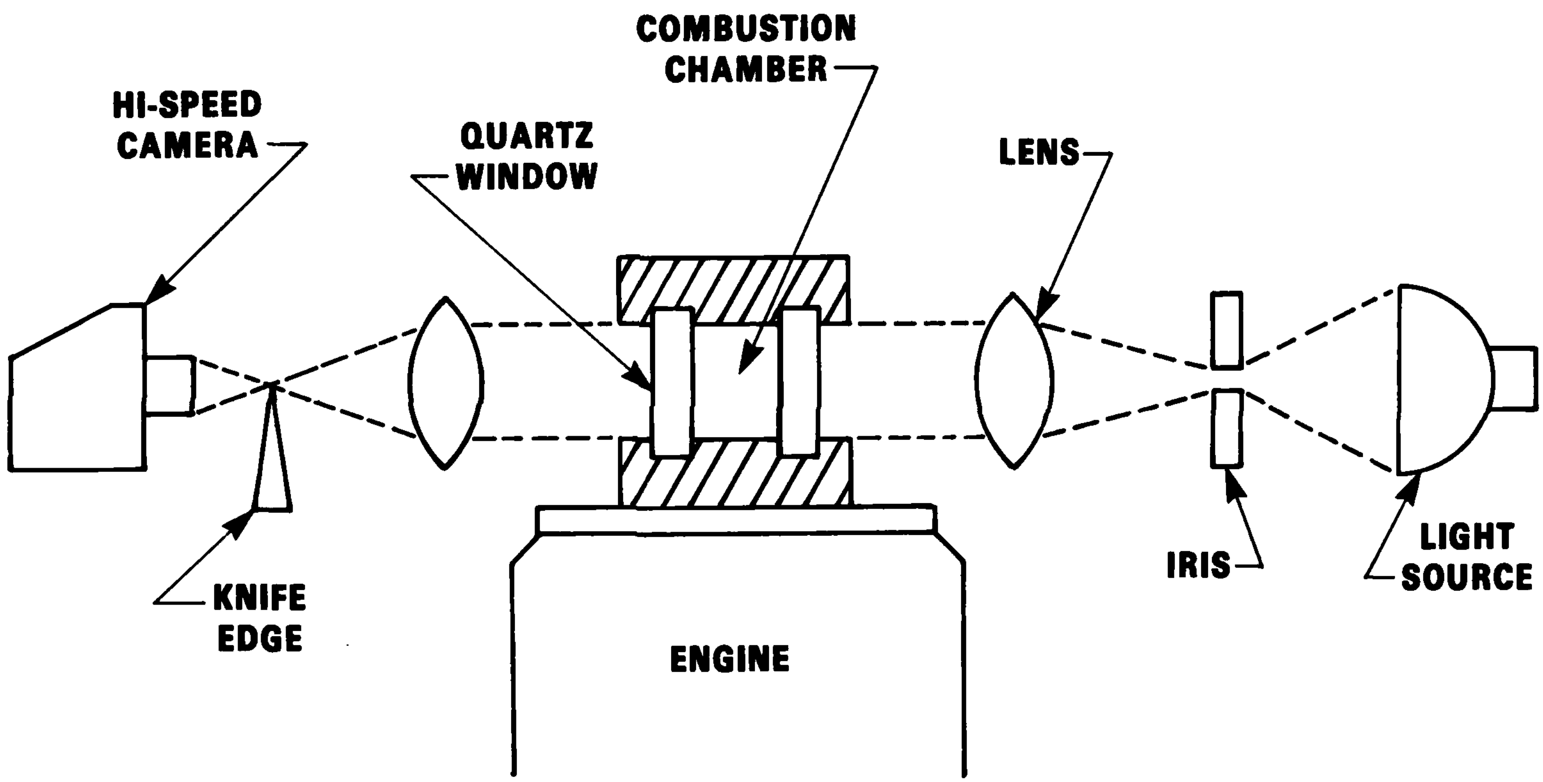
OBJECTIVE

TO GENERATE A HIGH-PRESSURE, HIGH-TEMPERATURE TURBULENT ENVIRONMENT IN WHICH TO STUDY:

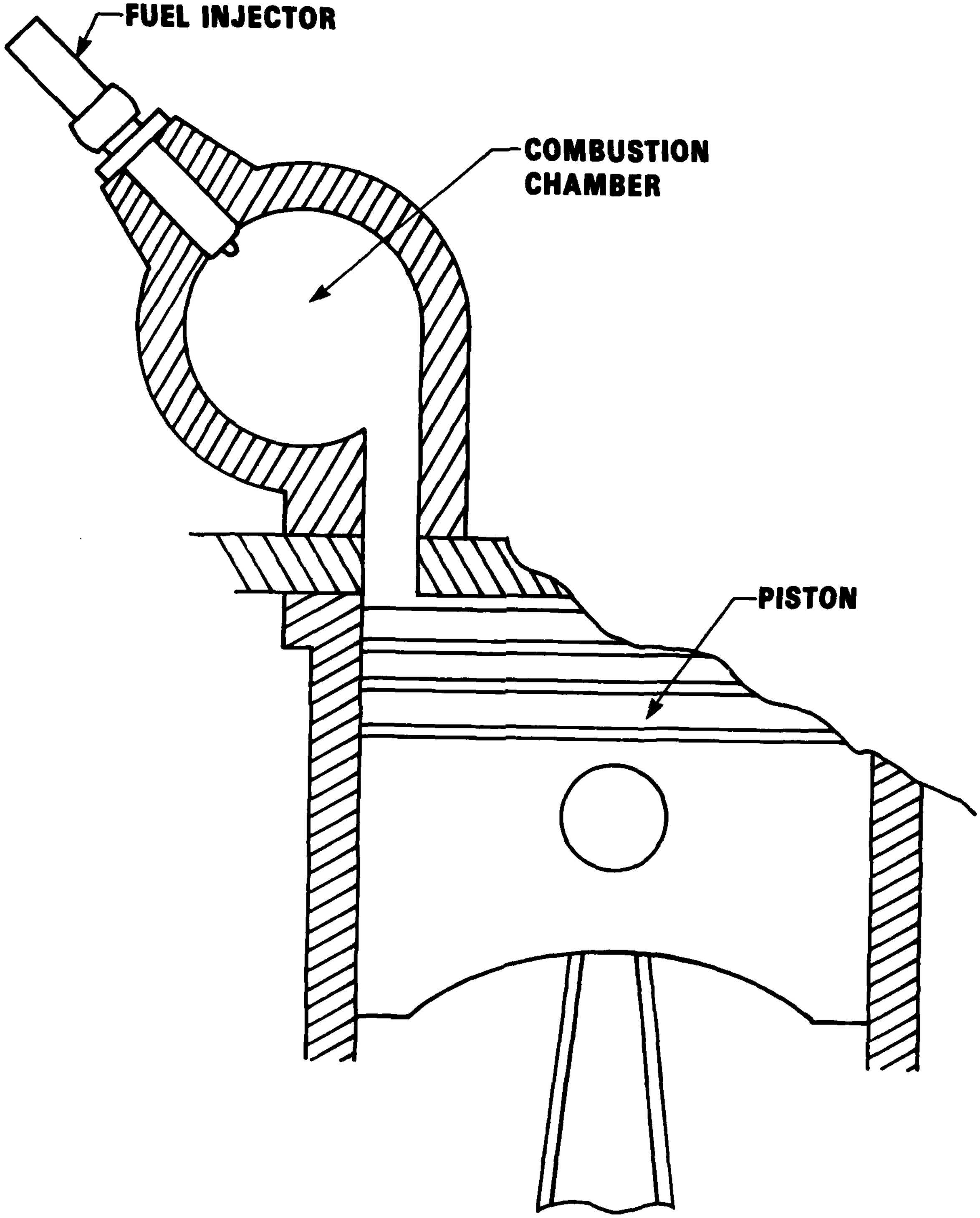
- **DIESEL INJECTION AND ATOMIZATION**
- **FUEL JET AND DROPLET EVAPORATION**
- **IGNITION**
- **COMBUSTION**



ENLARGEMENT OF THE COMBUSTION CHAMBER



OPTICAL ARRANGEMENT FOR HIGH-SPEED SCHLIEREN MOVIES



SCHEMATIC OF
PICTURE WINDOW ENGINE

ENGINE COMBUSTION/IGNITION FACILITY

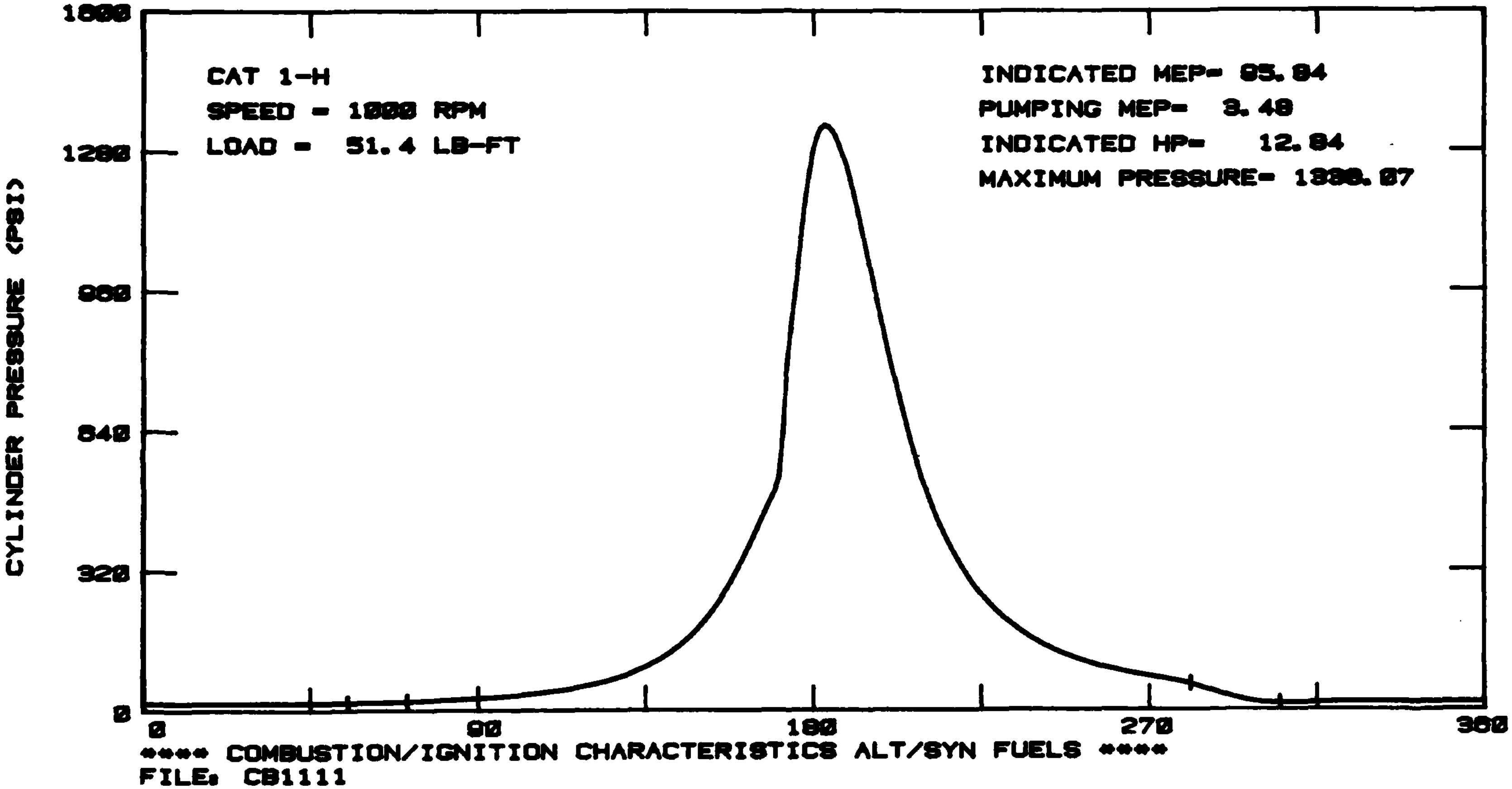
PROJECT MANAGED BY

E. C. OWENS

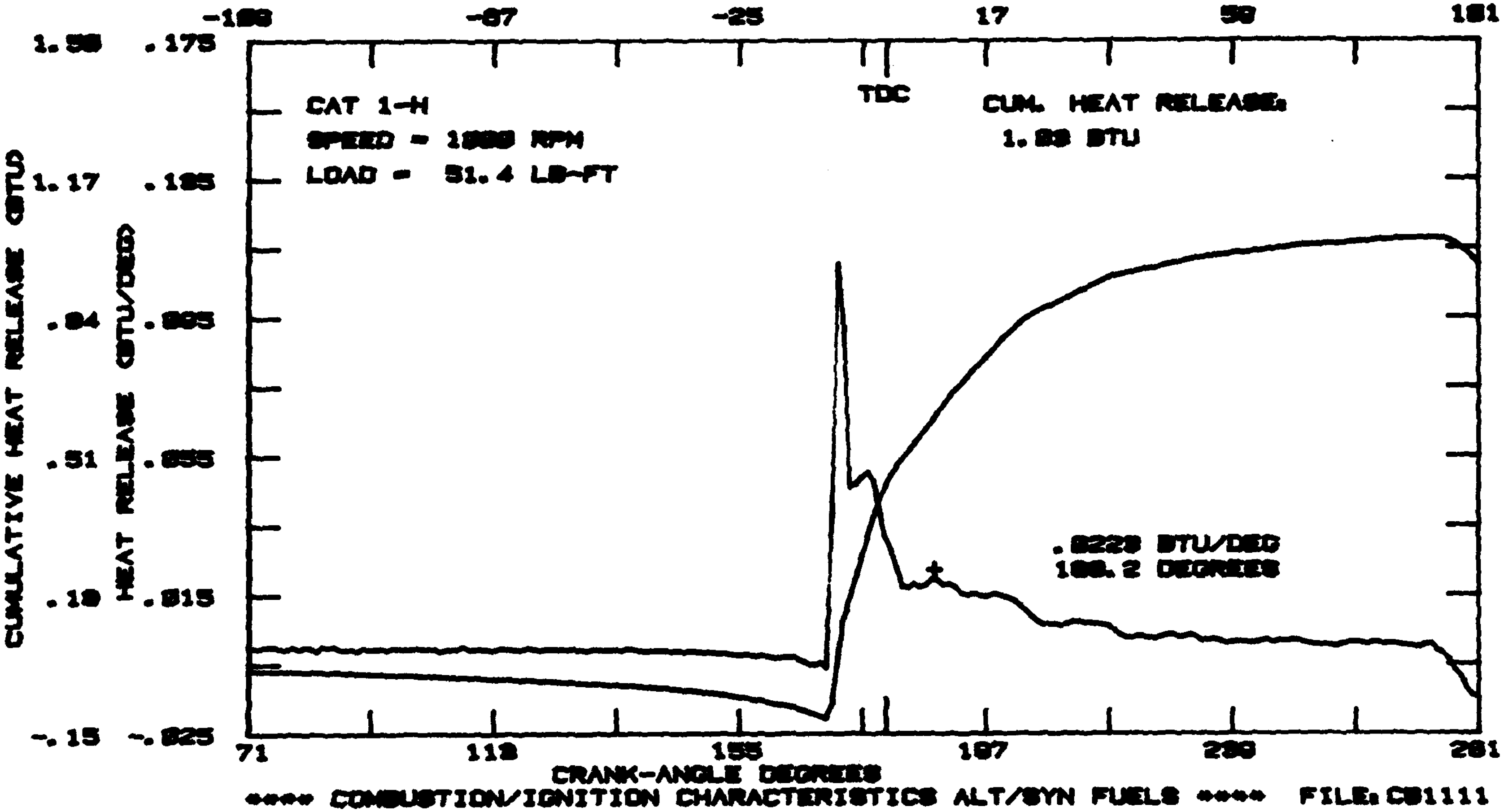
U.S. ARMY FUELS AND LUBRICANTS RESEARCH LABORATORY

OBJECTIVE

TO DETERMINE EFFECTS OF EXPECTED CHEMICAL AND PHYSICAL PROPERTY VARIATIONS OF ALTERNATIVE/SYNTHETIC FUELS ON DIESEL ENGINE PERFORMANCE



PLOT OF PRESSURE VS. CRANKANGLE



INSTANTANEOUS AND CUMULATIVE HEAT RELEASE PLOTS

ATOMIZATION AND EVAPORATION OF EMULSIFIED FUELS

PROJECT MANAGED BY

L. G. DODGE

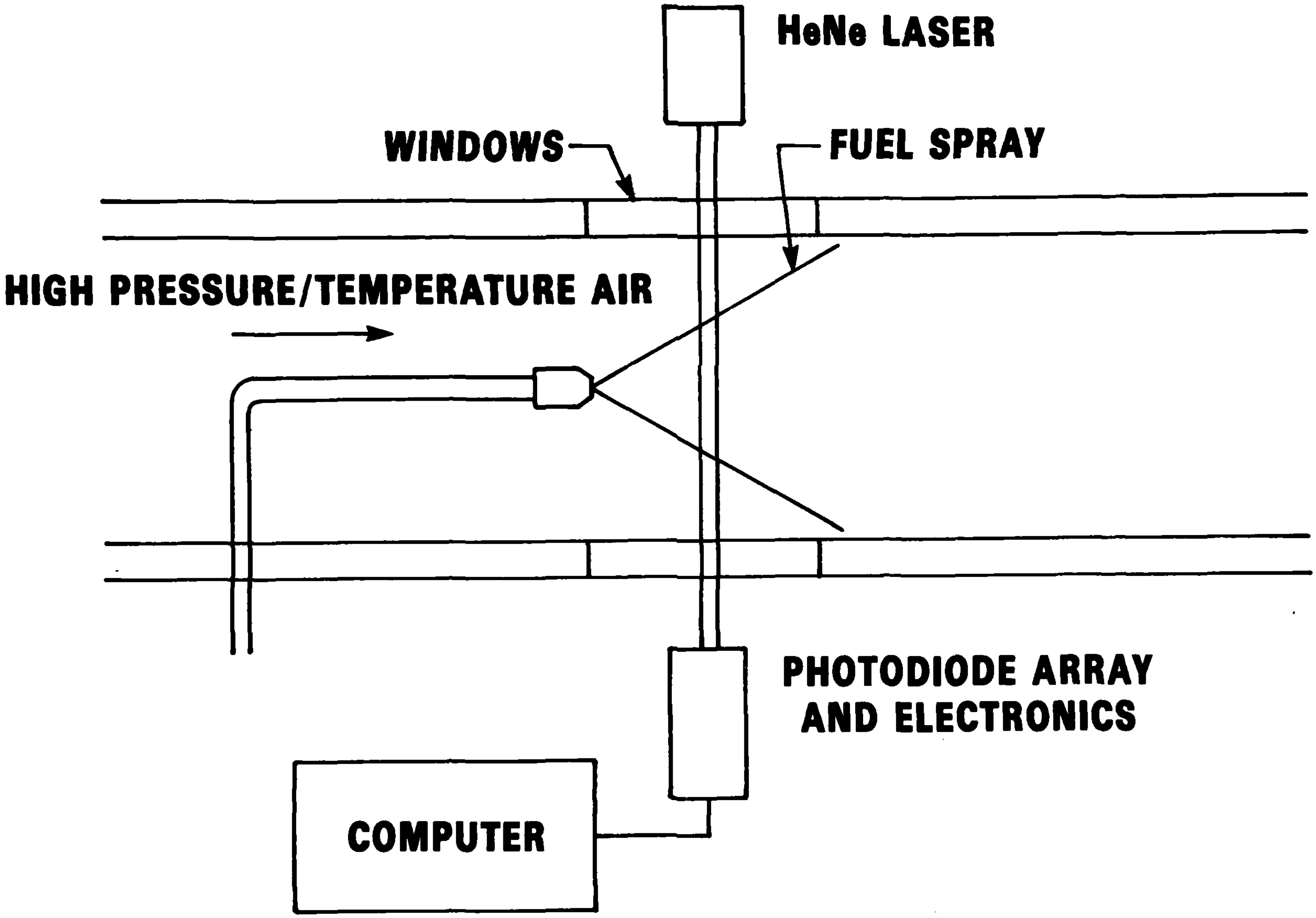
C. A. MOSES

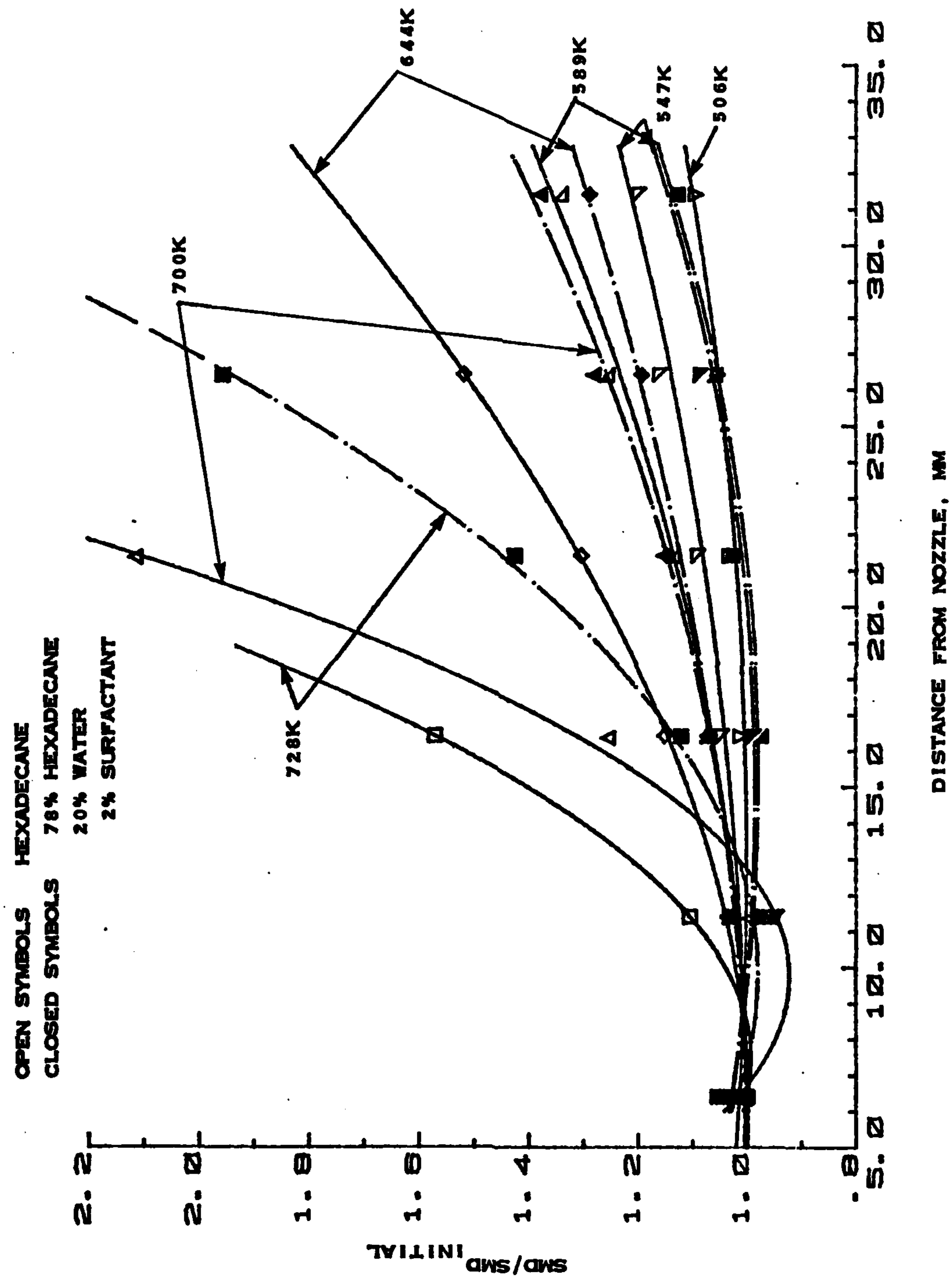
DEPARTMENT OF FUELS AND LUBRICATION TECHNOLOGY

OBJECTIVES

- DETERMINE IF MICROEXPLOSIONS OCCUR IN REAL SPRAYS OF EMULSIFIED FUELS AT ELEVATED PRESSURES, AND EXAMINE THE EFFECT ON THE DROP-SIZE DISTRIBUTION
- DEVELOP EXPERIMENTAL TECHNIQUES AND MATHEMATICAL MODELS TO DETERMINE THE EFFECTS OF VISCOSITY AND VOLATILITY ON ATOMIZATION AND EVAPORATION OF FUELS

DROP SIZE MEASUREMENT APPARATUS




OPEN SYMBOLS HEXADECANE
CLOSED SYMBOLS 78% HEXADECANE
20% WATER
2% SURFACTANT
728K
700K
644K
589K
547K
506K
SMD/SMD$_{INITIAL}$
DISTANCE FROM NOZZLE, MM
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
5.0
10.0
15.0
20.0
25.0
30.0
35.0

SUMMARY

- EMULSIFIED FUELS INITIALLY ATOMIZE SIMILARLY TO NEAT FUELS. AT HIGH TEMPERATURES/PRESSURES, THE EMULSIFIED FUELS PRODUCE SMALLER DROPS DOWNSTREAM FROM THE NOZZLE

- THE DIFFERENCES IN DROP SIZE

  – ARE ENHANCED BY INCREASES IN AIR PRESSURE

  – OCCUR AT PREDICTED DROP TEMPERATURES OF ABOUT 500K

  BOTH OF THESE ARE CONSISTENT WITH THE MICROEXPLOSION HYPOTHESIS

- EXPERIMENTAL TECHNIQUES AND COMPUTER MODELS HAVE BEEN DEVELOPED TO STUDY EVAPORATION OF ANY FUELS AT ANY TEMPERATURE AND PRESSURE

CARBON SLURRY FUEL DEVELOPMENT

PROJECT MANAGED BY

T. W. RYAN

DEPARTMENT OF FUELS AND LUBRICATION TECHNOLOGY

OBJECTIVE

TO DETERMINE THE EFFECTS OF VARYING THE PROPERTIES OF CARBON BLACK ON:

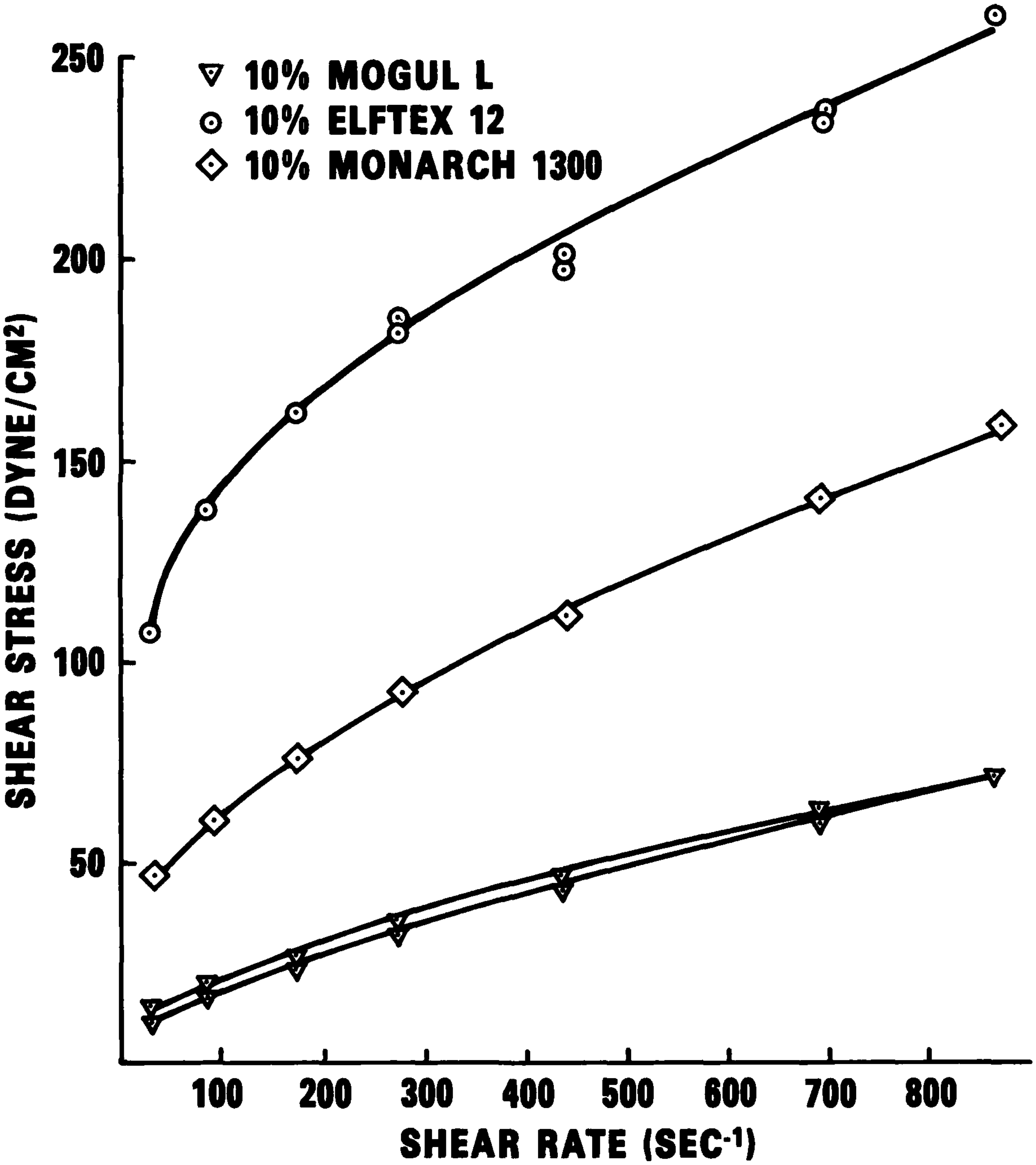
1. **THE PROPERTIES OF THE RESULTING SLURRIES**
2. **THE INJECTION AND ATOMIZATION CHARACTERISTICS OF THE SLURRIES**
3. **THE COMBUSTION CHARACTERISTICS OF THE SLURRIES IN A RESEARCH DIESEL ENGINE**

SLURRY FUEL PROPERTY EVALUATIONS

OBJECTIVE: TO DETERMINE EFFECTS OF CARBON BLACK PROPERTIES ON PROPERTIES OF SLURRIES

APPROACH: FORMULATION AND EVALUATION OF SLURRIES PRODUCED USING VARIETY OF DIFFERENT CARBON BLACKS

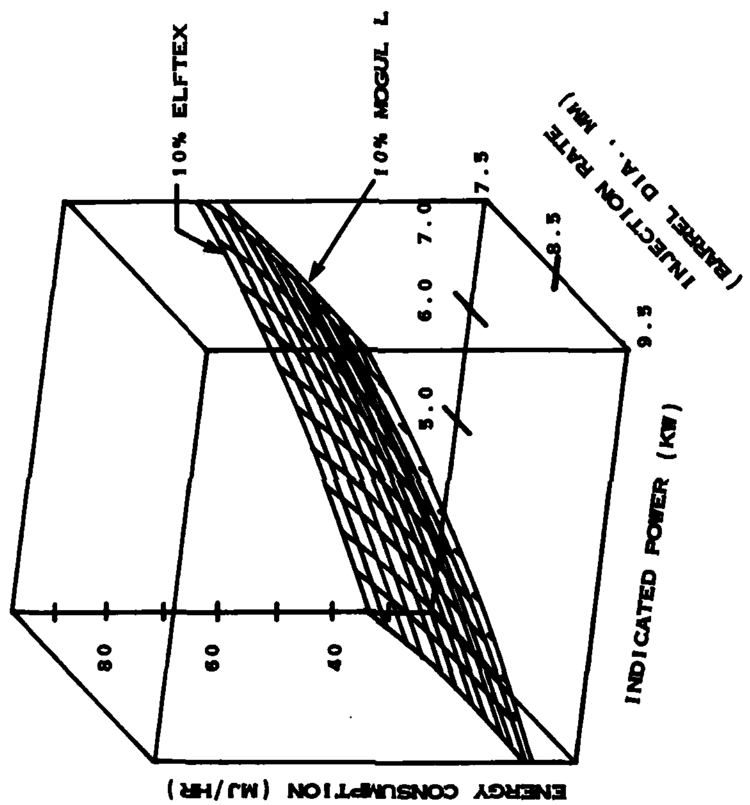
SHEAR STRESS VERSUS SHEAR RATE

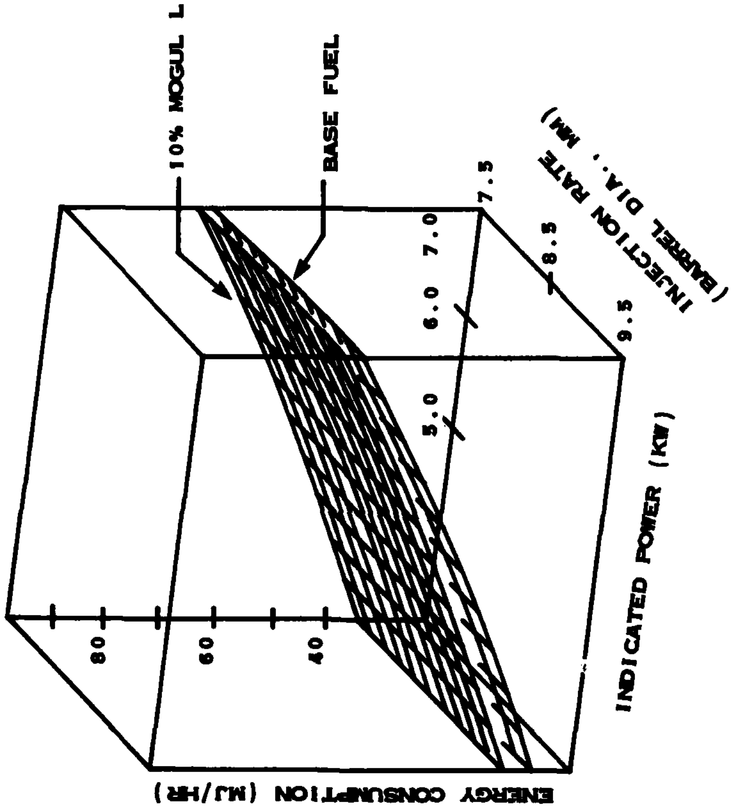


ENGINE EXPERIMENTS

OBJECTIVE: TO DETERMINE OPERATIONAL AND PERFORMANCE CHARACTERISTICS OF SLURRIES

APPROACH: SINGLE-CYLINDER, DIRECT-INJECTION CLR ENGINE EQUIPPED WITH HIGH-SPEED DATA ACQUISITION SYSTEM

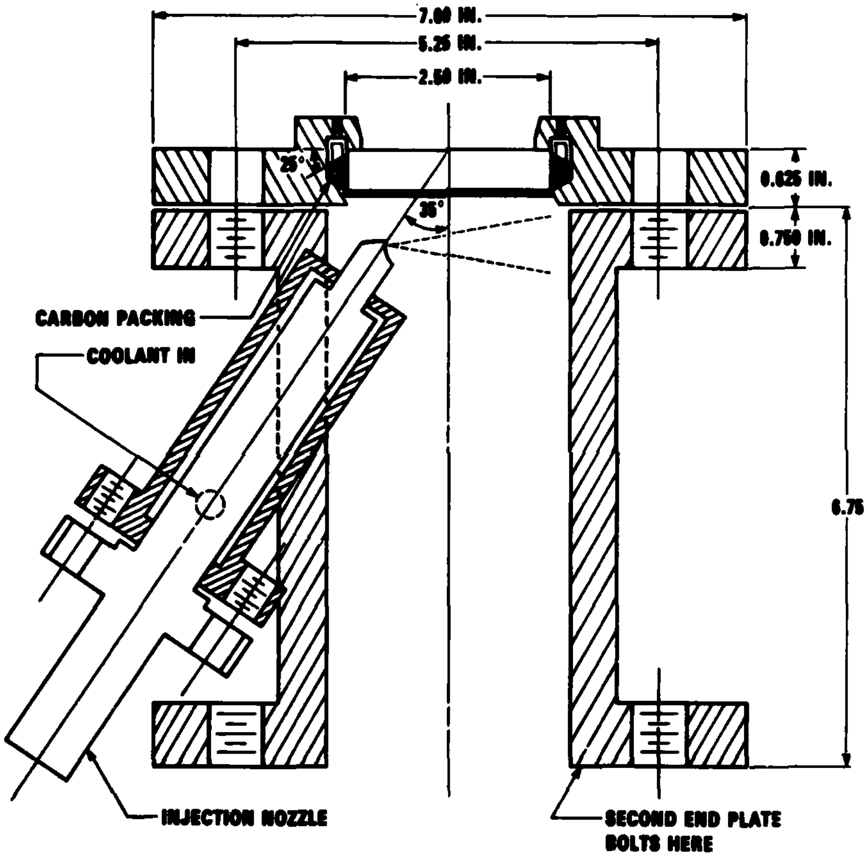

10% ELFTEX
10% MOGUL L
INJECTION RATE
(BARREL DIA., MM)
7.5
8.5
9.5
INDICATED POWER (KW)
5.0
6.0
7.0
ENERGY CONSUMPTION (MJ/HR)
80
60
40


10% MOGUL L
BASE FUEL
INJECTION RATE
(BARREL DIA., MM)
7.5
8.5
9.5
5.0
6.0
7.0
INDICATED POWER (KW)
40
60
80
ENERGY CONSUMPTION (MJ/HR)

INJECTION AND ATOMIZATION STUDIES

OBJECTIVE: TO INVESTIGATE EFFECTS OF CARBON BLACK ON DIESEL INJECTION AND ATOMIZATION PROCESS

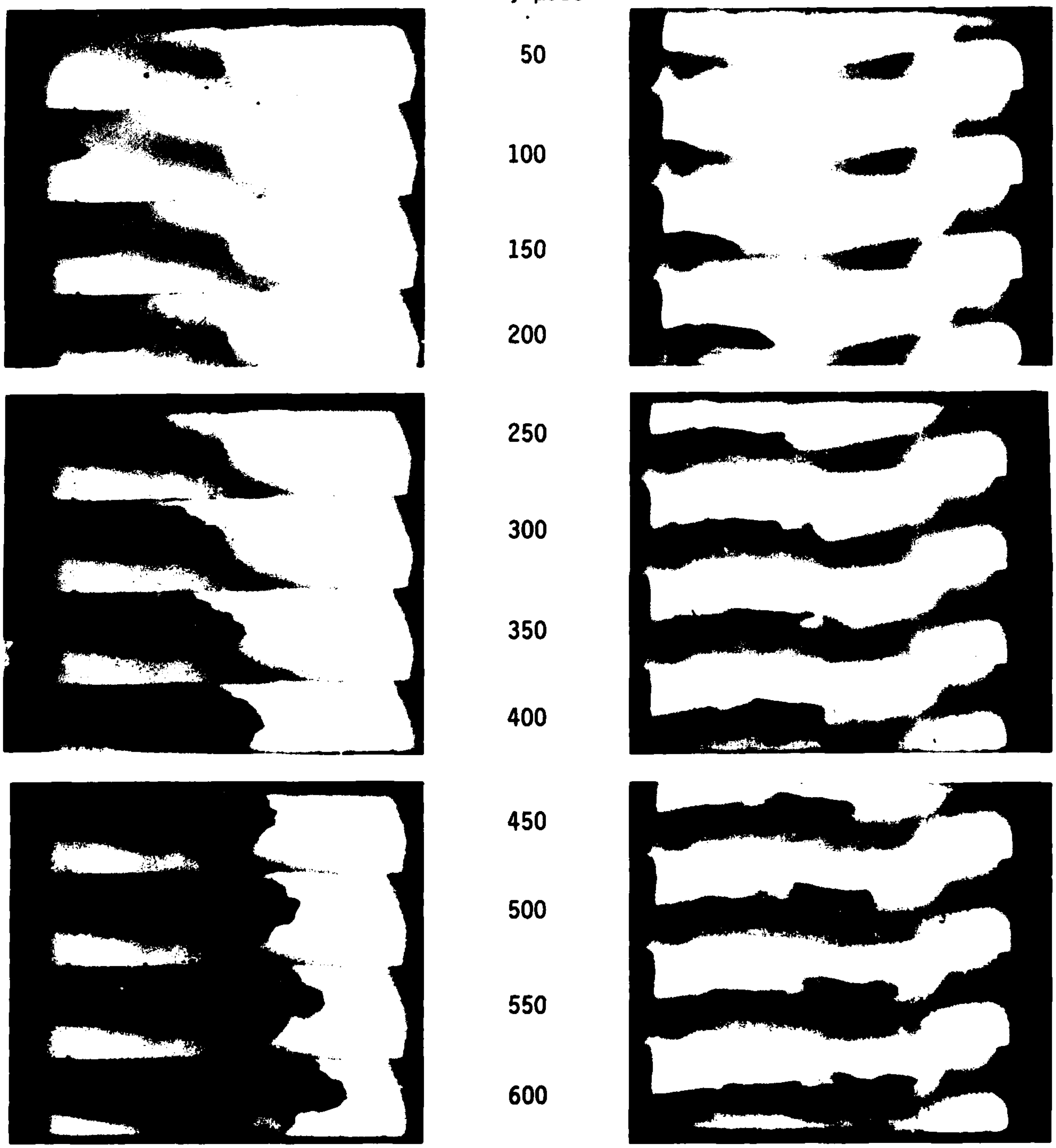
APPROACH: DESIGN OF A DEVICE WHICH ALLOWS FOR VISUAL OBSERVATION OF INJECTION EVENT



INJECTION AND ATOMIZATION BOMB

COMPARISON OF FUEL INJECTION BETWEEN
NEAT DIESEL AND 20% MOGUL L SLURRY, 174 PSIG, 80°F
(50 to 600μsec)

BASE FUEL NEAT DIESEL | TIME, μsec | 20% MOGUL L SLURRY



OUTSTANDING QUESTIONS

- HOW DOES THE PRESENCE OF THE SOLID PARTICLES AFFECT THE INJECTION, ATOMIZATION, IGNITION, AND COMBUSTION OF THE LIQUID COMPONENT OF THE SLURRIES ?
- WHAT ARE THE MECHANISMS FOR IGNITION AND COMBUSTION OF THE SOLID PARTICLES IN DIESEL ENGINES ?
- WHAT IS THE OPTIMUM CONFIGURATION OF THE SOLID PARTICLES FOR FUEL FORMULATION ?

Session 6
DISCUSSION GROUPS

on

- **Reciprocating Engines/Fuels**
  Leader: S. S. Lestz
  Penn State University
  University Park, PA

- **Turbine Engines/Fuels**
  Leader: A. M. Mellor
  Drexel Univesity
  Philadelphia, PA

END

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